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ALASKAN AIR NAVIGATION REQUIREMENTS. VOLUME I. OVERVIEW.(U)
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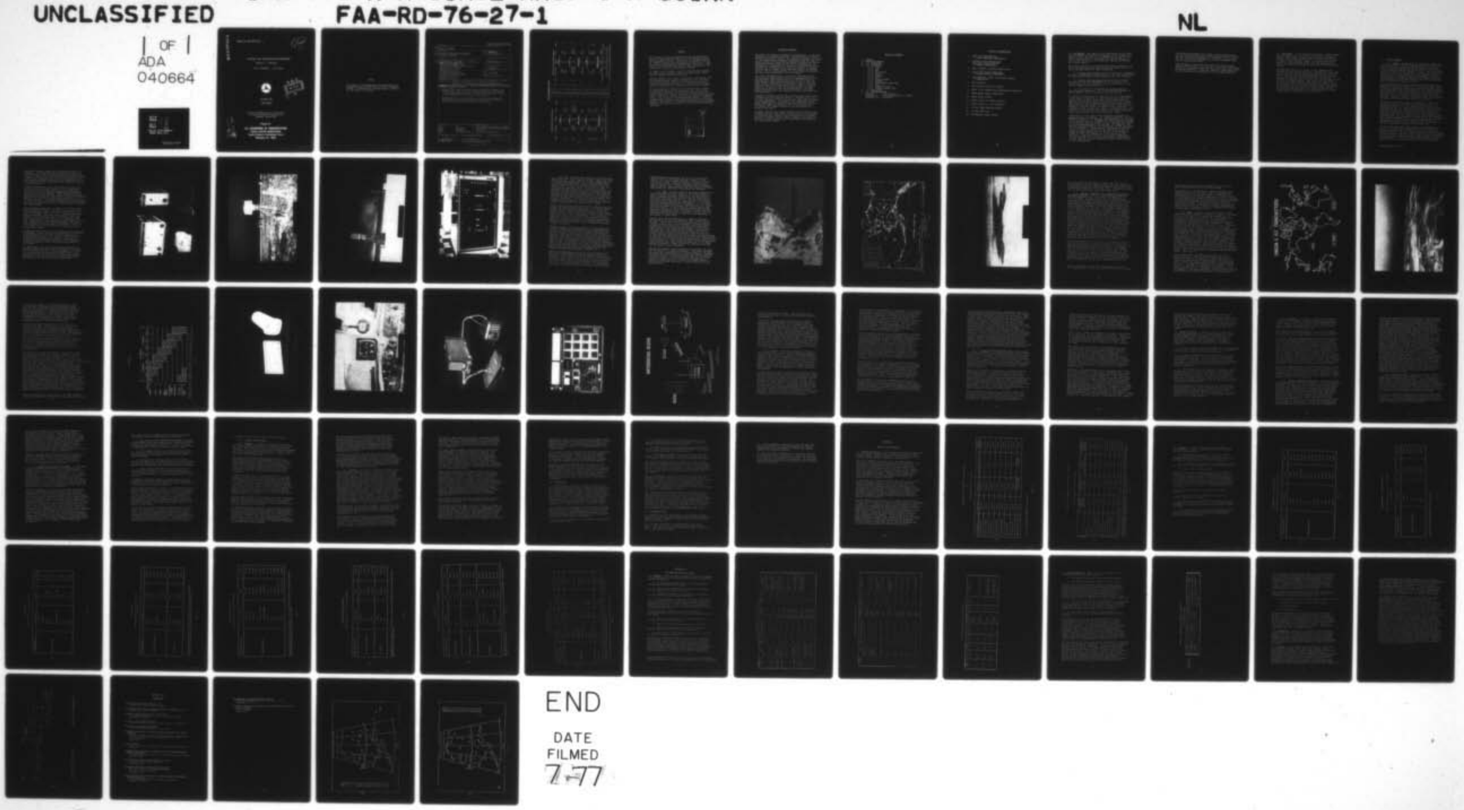

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ALASKAN AIR NAVIGATION REQUIREMENTS

Volume I -- Overview

A.A. Simolunas G.H. Quinn

January 1977

Final Report

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D.C. 20590

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VOLUME III - "FAA ALASKAN VHF OMNI-DIRECTIONAL RANGE VOR SITE COVERAGE" was prepared by the Electro-Magnetic Compatibility Analysis Center (ECAC) of Annapolis, Maryland.

16. ABSTRACT - This report describes the unique air navigation problems of the Alaskan Region. Present and future navigation aids are described relative to their applicability to this area. Conclusions as to the near term and far term feasibility of these alternatives are summarized.

Recommendations for a near term solution are presented using VORTAC, NDB, and DME systems. An operational feasibility system using Differential Omega is also described for a possible far term solution.

17. Key Words

NDB	DME
VORTAC	NAVSTAR/GPS
Omega	VLF/NAVCOM
Loran-C	Differential Omega

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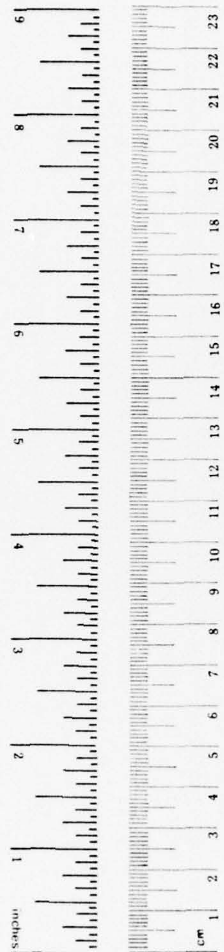
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

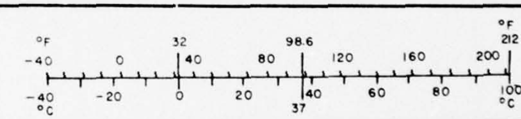
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This report has been prepared by the Enroute Navigation Branch of the Navigation Division of the Systems Research and Development Service. This effort is sponsored by the Air Traffic Control Service under FAA Form 9550.1, "Study of Alaskan Air Navigation Requirements," AAT-100-28. This report deals with both near and far term solutions to the Alaskan air navigation requirements problem.

In support of this effort, two (2) contracts were awarded. For this reason, separate additional stand-alone reports will be issued as Volumes II and III.

Systems Control, Inc., (SCI) of Palo Alto, California, and their subcontractor Champlain Technology, Inc., of Fort Lauderdale, Florida, has performed the near term benefit analysis contained in Volume II. This effort deals with the near term solutions in greater detail than in Volume I.

The Electromagnetic Compatibility Analysis Center (ECAC) of Annapolis, Maryland, has developed the line-of-sight signal charts contained in Volume III which include the VORTAC coverage at various altitudes of existing and proposed sites. Due to the lack of terrain data north of Fairbanks, normally supplied by the Defense Mapping Agency, a special method using a chromatic extraction technique was developed by ECAC. This data, in conjunction with present and proposed VORTAC sites, was then utilized to develop the VOR coverage overlays.

EXECUTIVE SUMMARY

The unique environmental problems of Alaska have, in the past, resulted in a difficult problem in the selection of a cost-effective navigation system. Air demands to support the recent oil and other natural resource requirements and the lack of other alternative transportation modes to service the diverse population centers result in the serious consideration of implementing a comprehensive navigation network which cannot entirely be justified by the resulting increase in traffic. Alternatives of VORTAC, TACAN, NDB, DME, Omega, VLF NAVCOM, Loran-C, GPS, and combinations of the above were considered. The short term requirements are also defined.

This study recommends that a short term (NDB/DME/VORTAC) and long term (Omega/DME) solution be implemented to avoid the extremely high implementation and O&M costs which a comprehensive VORTAC system would entail and, at the same time, allow a progressive replacement of current avionics (NDB and VOR) with Differential or basic Omega; if proven feasible. This will allow an interim approach of using either basic Omega or VLF NAVCOM immediately. The DME hybrid approach would also upgrade the basic NDB system at selected sites.

A number of VORTACs can be added to those areas which serve international and interstate traffic. VORTACs to fill in the high altitude structure by aircraft using RNAV equipment is also recommended. If possible, the implementation of these VORTAC stations should be delayed until the new 2nd Generation VORTAC is available due to the eventual plan to retrofit all VORTAC stations in the near future to minimize O&M costs.

If Omega does not prove to be feasible due to technical or economic factors, this VORTAC alternative could be expanded as necessary until another long term solution is selected. The use of TACANs instead of DMEs at NDBs is acceptable if offshore oil platform and other requirements are supported by a significant demand.

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1.0 BACKGROUND. The advent of oil exploration on the North Slope of Alaska has shown the inadequacy of the present navigation service, not only in that remote region, but for the entire Alaskan Region. This report has been developed to explore the alternatives available for solving this problem in a timely manner.

There are three major user groups which have indicated a need for a more precise and reliable navigation system for the entire Alaskan Region for IFR applications:

A. Pipeline installations which are served by independent air carrier companies. Their operations will use approximately 20 flight strips from the North Slope to the Port of Valdez.

B. The oil drilling operations served by helicopter operations, which are independent of the pipeline, will include sites on the North Slope as well as offshore in the Gulf of Alaska and the Bearing Sea.

C. The commercial, scheduled air carriers and air taxi operators, which serve the general population over the entire state of Alaska, including Aleutian Islands.

In addition, recognizing the importance of air transportation to the general population in this remote region, the rather large general aviation group which use VFR techniques in combination with NDBs should also benefit from this improvement since they may be burdened with a greater share of the system costs in the future. Decommissioning these facilities without an adequate substitute would not be in the best interests of the largest user segment. Exploration for other minerals and and gas pipline construction through Canada are other factors which could have significant impact.

Independent of this study, three different techniques are presently being considered: (1) TACAN proposed by a Sierra/MONTEK (E-Systems), (2) DME/NDB being implemented by the pipeline interests, and (3) a network of VORTAC stations proposed by the Alaskan Regional Planning Group. Although there seems to be some disenchantment with the very low frequency (VLF NAVCOM) techniques used by the GNS-200/500 (Global Navigation, Inc.) and ONTRAC II (Communications Components Corporation) because one station critical to the acceptance of VLF in Alaska has been temporarily off the air, a considerable number of users are considering or have opted for this technique. Omega has also been given little attention up to this time due to the lack of operational transmitters. Loran-C coverage does not presently include a major portion of the required area.

It should be recognized that present pipeline installation and oil drilling efforts will reach a peak within five years and then taper off substantially. Therefore, a short term solution is actually required to allow this important activity to proceed efficiently.

Also, Alaska, as previously mentioned, has other natural resource efforts such as the natural gas pipeline construction which will need support over the long term. This aspect must be considered before a temporary system is implemented that cannot be practically converted to a long range solution.

2.0 DISCUSSION. In the following discussion, NAVAID systems will be divided into two general categories: primary and hybrid. The primary system consists of those techniques already widely used and which are, to some degree, already in place. Other systems, namely in the VLF-LF frequency bands, are also discussed since their implementation is already in progress and will be available in the foreseeable future.

Although satellites are a factor in the communications approach of this study, their use in navigation is not firm due to the fact that implementation has not been initiated and that avionics costs, especially from the low cost user aspect, has not been adequately defined. This is not intended to minimize this alternative as the eventual replacement for the VORTAC system. But, the use of the Global Positioning System (GPS) as proposed by DOD seems to be far in the future to solve Alaska's problem in the next twenty years unless some strategy using a ground/space combination is developed that would allow a gradual transition to a primary space-based system. The problem with this option is discussed in further detail in this study.

2.1 PRIMARY SYSTEMS.

2.1.1 TACAN. The Tactical Air Navigation System is a rho/theta system initially developed for military use and is still used as an en route navigation system. The range function has been adopted by the civil sector in the form of the Distance Measuring Equipment (DME). The FAA is still required to maintain this system* in support of DOD and will continue until a full transition to GPS (estimate 1990+). Approximately 700 TACAN stations are presently co-located with VOR and are commonly referred to as VORTAC stations as differentiated from VOR/DME stations which do not have the bearing capability inherent to TACAN.

The TACAN system operates in the 900-1200 MHZ frequency as compared to the 105-115 MHZ range of the VOR system. This allows a considerable reduction in antenna size and siting preparation which was a basic necessity for military tactical use as opposed to civil requirements. This factor could be important to the operational environment found in Alaska especially for oil platform installation where space is at a premium. Temporary (mobile) installation such as a pipeline construction site could also utilize this feature.

In general, the TACAN system has a number of attractive attributes besides its compact ground station size. The airborne equipments are also simplified since only one frequency is used for both range and bearing which, in turn, necessitates only one antenna installation. The effects of solar and atmospheric disturbances are also minimal as compared to the VLF-LF frequency band. Past studies have also indicated that the accuracy of the TACAN bearing system is better than that attainable with the VOR or NDB systems. Since airborne components are an integral part of the present DOD systems, having already passed the development and implementation phases, their relative cost, as compared to VLF-LF or satellite systems, are generally low.

On the other hand, TACAN does possess the disadvantage of being a "line-of-sight" system which not only limts its coverage capabilities, but also increases the reflective properties of its signals. Unlock and false lock-on problems are not uncommon. The ultra-high frequency band also requires relatively higher power than VOR or NDB stations for equivalent coverage. In addition, the bearing (theta) avionics capability does not exist outside the DOD aircraft fleet

*both bearing and range

and would require a substantial investment by the civil community. A system has just recently been marketed by Sierra Research, Inc., the SANS 705 which is depicted in Figure 1. The reliability of high frequency/pulsed systems is often criticized but they do have the capacity to be designed using digital techniques with automated built in test equipment (BITE) which would lower MTTR and, in turn, maintenance costs.

Another consideration, even though remote at this time, is the fact that "L" band region is a very attractive frequency and is presently being actively developed by DOD for its future Integrated Communications/Navigation/Identification (ICNI) systems. These systems are being designed to be compatible with TACAN and future developments involving air-to-air and ground-to-air data links. In addition, the FAA is currently investigating the feasibility of precision DME, high capacity DME and digital data broadcast which is compatible with the TACAN system and possibly with GPS/NAVSTAR.

Tests have been conducted at a number of difficult sites with the MONTEC AN/TPN-26. Figure 2 is an illustration of this equipment. These tests were performed at Cook Inlet, Anchorage, Valdez, and Kenai. Similar tests have been held at Aspen, Colorado, in conjunction with Aspen Airways. It is understood that the Alaskan tests were quite successful but this fact is not confirmed at this time. Operations by Aspen Airways has been approved after some modifications to the ground equipment. The model with a shelter is now marketed at the M-6000. Also, one of the major oil rigs in the Gulf of Alaska shall also utilize this system.

A number of developments have also been recently completed by FAA/SRDS. These include the development of false lock-on modifications, solid-state retrofit components, an improved weather radome (See Figure 3) and an improved antenna with a higher signal gradient. Antennas and electronic ground equipment modifications to double the available frequency channels have also been developed (Y-Channel).

The development of a digital solid-state TACAN with an automated remote monitor/diagnostic capability has also been initiated by the FAA. This development, if successful will minimize the maintenance problems which are a serious constraint for the type of remote sites common to Alaska. Figure 4 depicts a solid-state DME recently developed for the FAA for terminal applications.

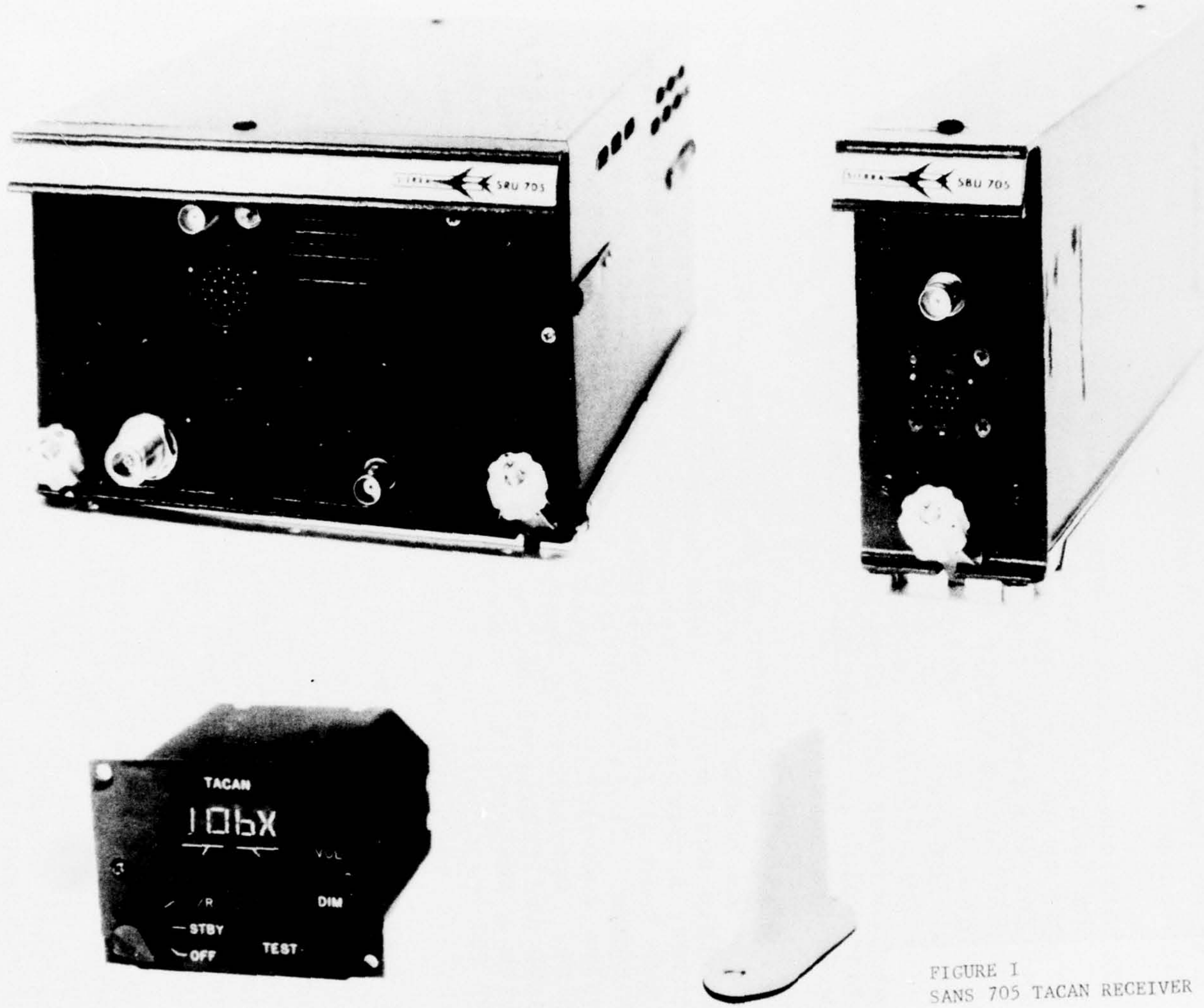


FIGURE I
SANS 705 TACAN RECEIVER

FIGURE 2

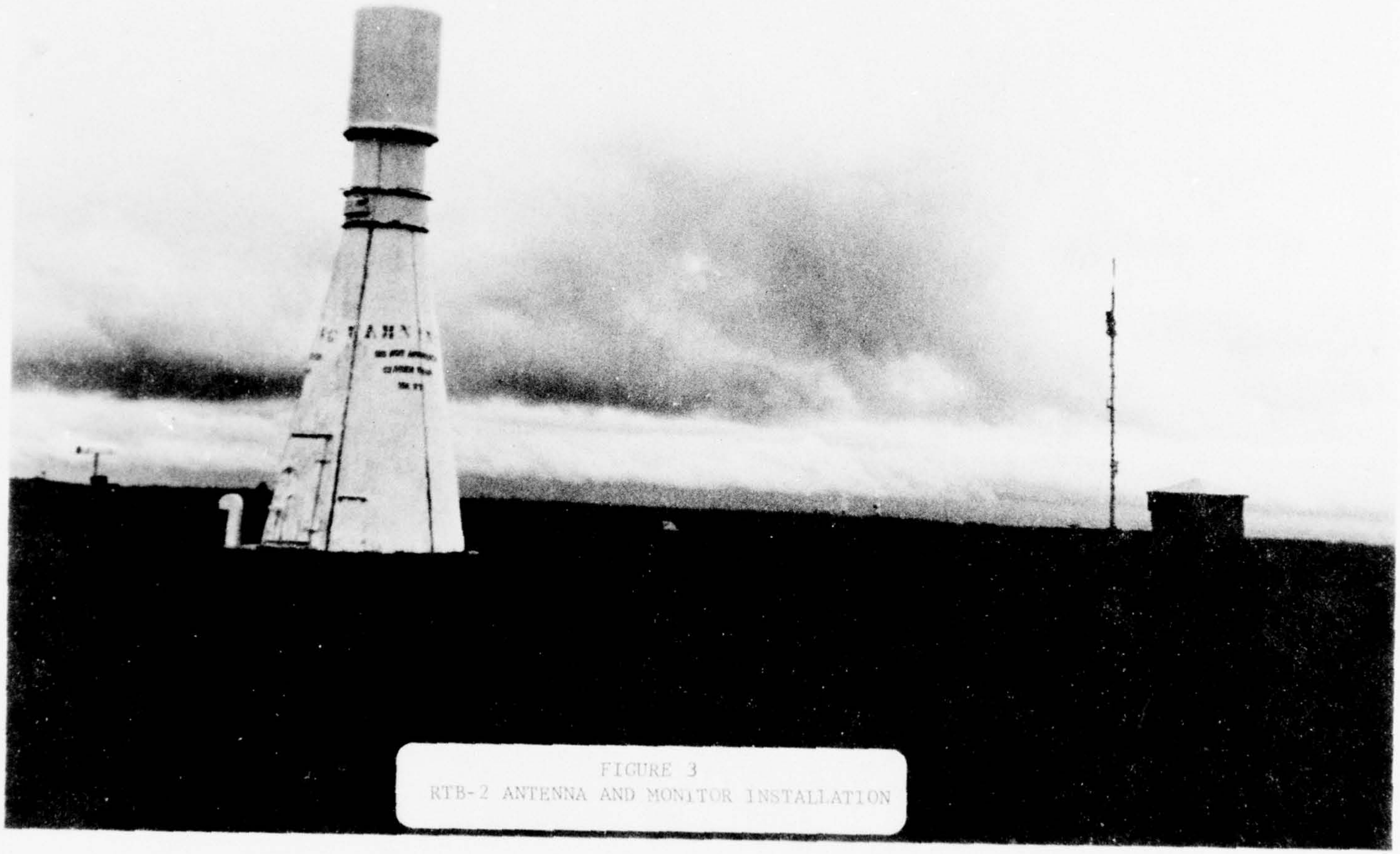


FIGURE 3
RTB-2 ANTENNA AND MONITOR INSTALLATION

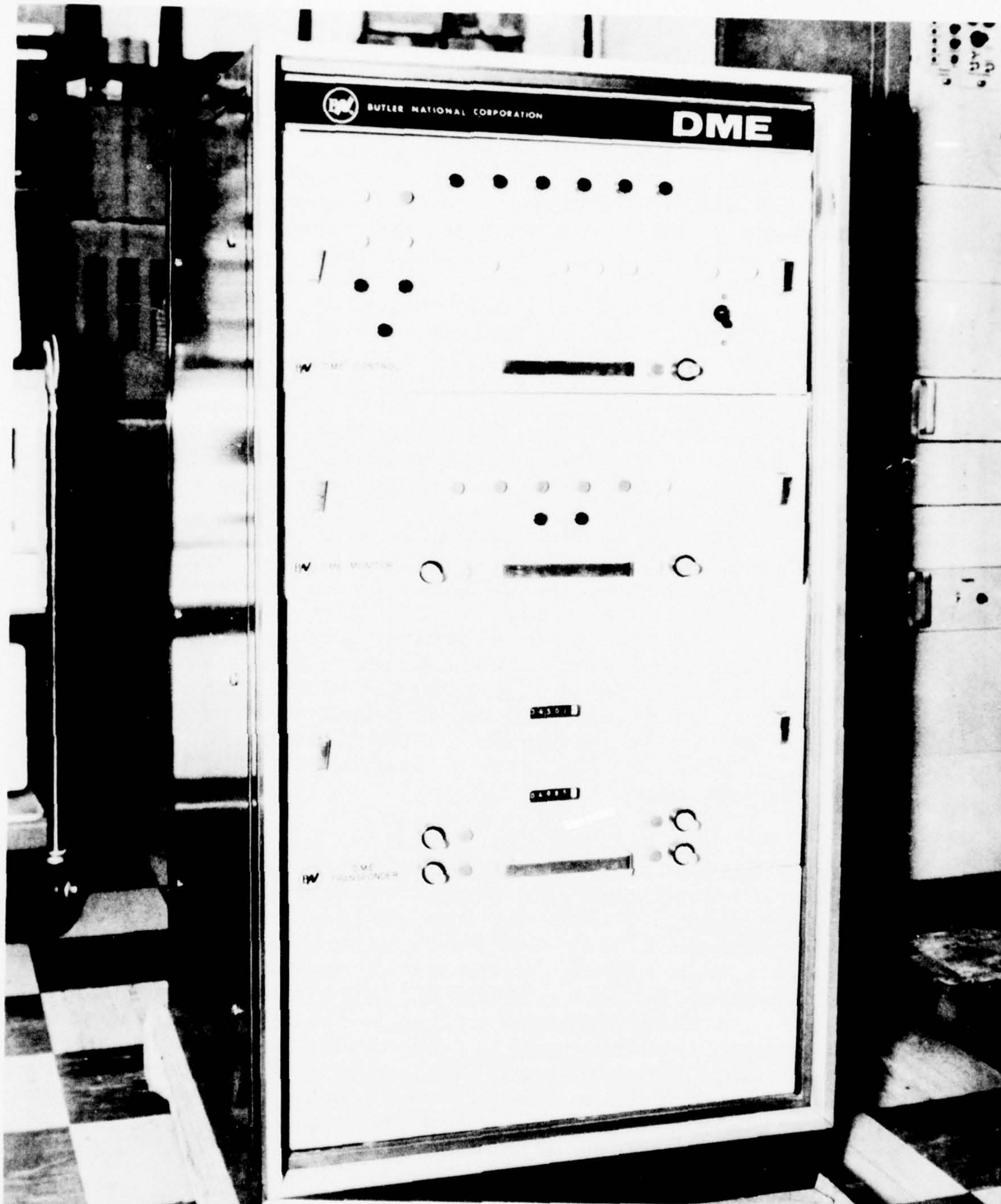


FIGURE 4
BUTLER SOLID STATE DME

2.1.2 VOR. The Very High Frequency Omni-Directional Range (VOR) is a theta (bearing) system. Range (rho) data is furnished by either a DME or the range subsystem of a co-located TACAN equipment. This frequency band (VHF), as previously stated, does have the advantage over the TACAN (L) band in that its service volume is larger for an equivalent radiated power. In addition, its low frequency continuous wave operation has historically been the more reliable system as compared to TACAN, both from the airborne and ground equipment aspect. Also, VOR is probably the most common navigation avionics installed in aircraft at this time, which is obviously important from a user's standpoint. Its frequency relation to the communications frequencies are an added economic benefit from the installation and common circuit aspect.

On the other hand is the fact that this system (as well as TACAN) has line-of-sight limitations. This would require a considerable number of VORTAC stations to cover the Alaskan Region. VOR siting is also more difficult than TACAN which requires a considerable amount of site preparation as well as a large counterpoise. This naturally requires land access to the site for construction equipment and a significant amount of foundation preparation which is extremely expensive in the Alaskan Region. The effects of snow and ice also cause considerable problems in the siting area.

Figures I-1 and I-2 are the locations of the current and proposed VORTAC sites recommended by the Alaskan Region. In order to determine the signal coverage resulting from this deployment, a contract was awarded to the Electromagnetic Compatibility Analysis Center (ECAC) in Annapolis, Maryland. This effort, using an automated technique, produces coverage plots at different altitudes. This process uses terrain data produced by the Defense Mapping Agency (DMA) of DOD. Unfortunately, those areas north of Fairbanks have not been processed and DMA could not develop the required data in time for this study. Therefore, ECAC manually produced this data from color-coded topography maps. The results are shown and discussed in Volume III.

Research and Development efforts to minimize some of the above-mentioned system deficiencies have been recently initiated. These include the development of high gradient stacked antennas (5-bay) for use in difficult sites in lieu of Doppler VOR. Also, the development of highly reliable solid-state VOR with an automated monitor and diagnostic capability is also presently in process. The development will reduce maintenance costs significantly and will make

VORTACs much more attractive for use in an environment such as found in the Alaskan Region. Figure 5 is an example of a 5-bay stacked array which will be evaluated in the near future. Previous efforts to develop this type of antenna have not been successful due to excessive bearing errors. Major advances have been made to minimize this effect but additional evaluations are necessary.

2.1.3 NDB. The FAA currently maintains approximately 57 Non-Directional Beacons (NDB) in the Alaskan Region. About 85 others have been installed or are maintained by other government agencies which include the Coast Guard, Navy, AEC, Air Force, and the FCC. Figure 6 depicts the location of these facilities. Bechtel, Inc., in conjunction with Alyeska Pipeline Service Company, is also under contract with Wilcox Division of Northrop, Inc., to install this type of NAVAID at selected construction sites along the oil pipeline. It should also be recognized that NDB deployment throughout the United States is quite extensive; numbering approximately 500. Therefore, avionics and ATC procedures are quite common as well as pilot awareness of the system's capabilities.

Despite these obvious advantages, a number of problems are prevalent to these low frequency (LF) systems (200 to 400 KHZ). Although an aircraft equipped with a direction finding receiver using a loop antenna can achieve bearing accuracies of approximately 1.0° under ideal conditions, needle swings of 20° could be encountered in the service area and 10° in the final approach sector. Studies have indicated that this phenomena is very sensitive to the remote terrain features in proximity to the aircraft and is only slightly improved with site selection or modification. In addition, monitoring bearing errors from near field monitors have proved to be difficult and not indicative to the stations overall operation. This requires frequent flight checks and/or field monitors with their attendant high costs. For these reasons, automated - remote monitoring techniques for NDBs are not being actively developed.

Weather and seasonal ground conductivity problems also limit the reliability of a NDB based system. Sky effect problems have also been noted which are a serious problem in frequency management and could drastically limit the further expansion of this technique. Since only bearing data can be derived from these facilities, pilot workload, coverage gaps, its inherent instability due to terrain and weather factors makes this technique (NDB only) a rather unattractive long term solution.

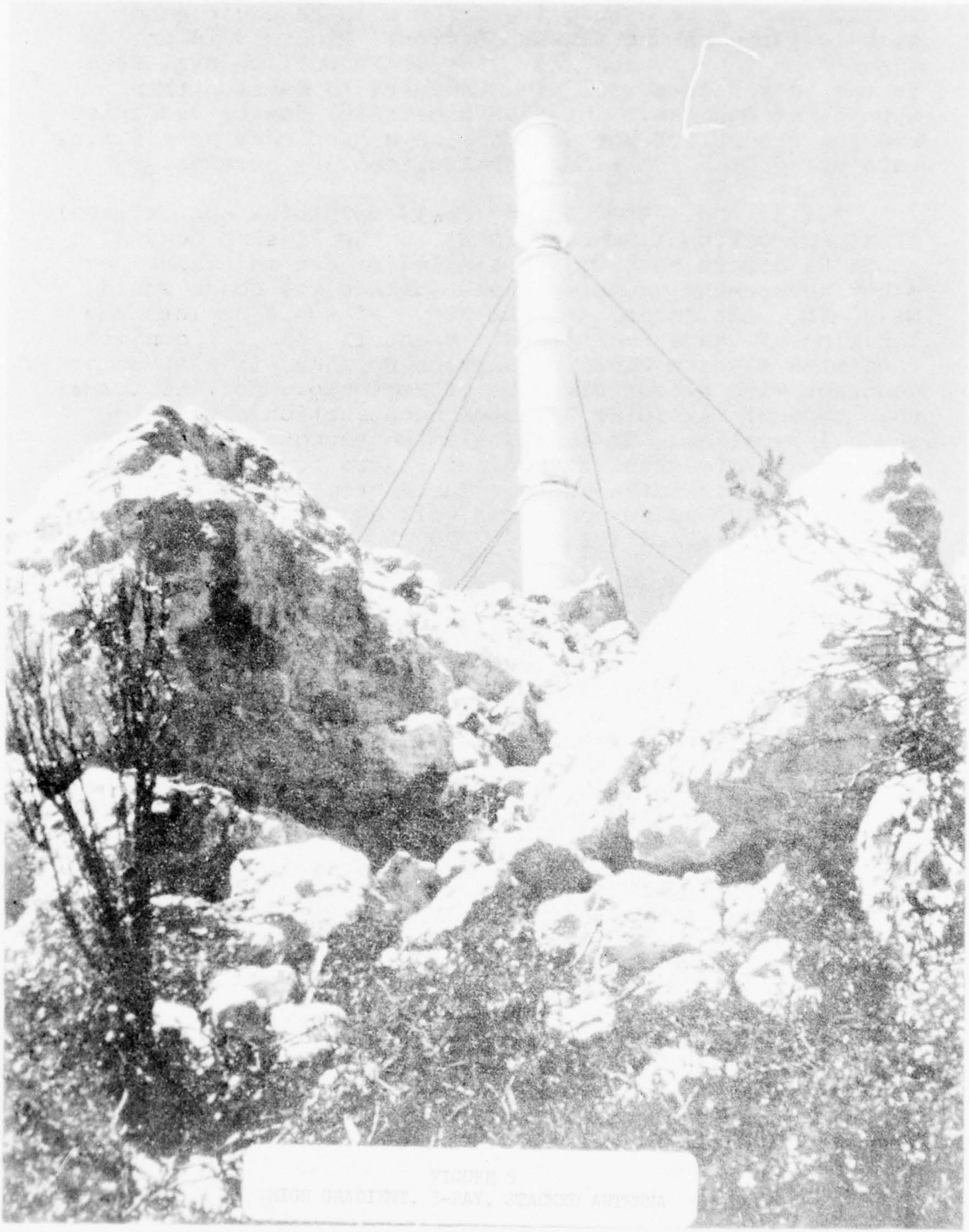
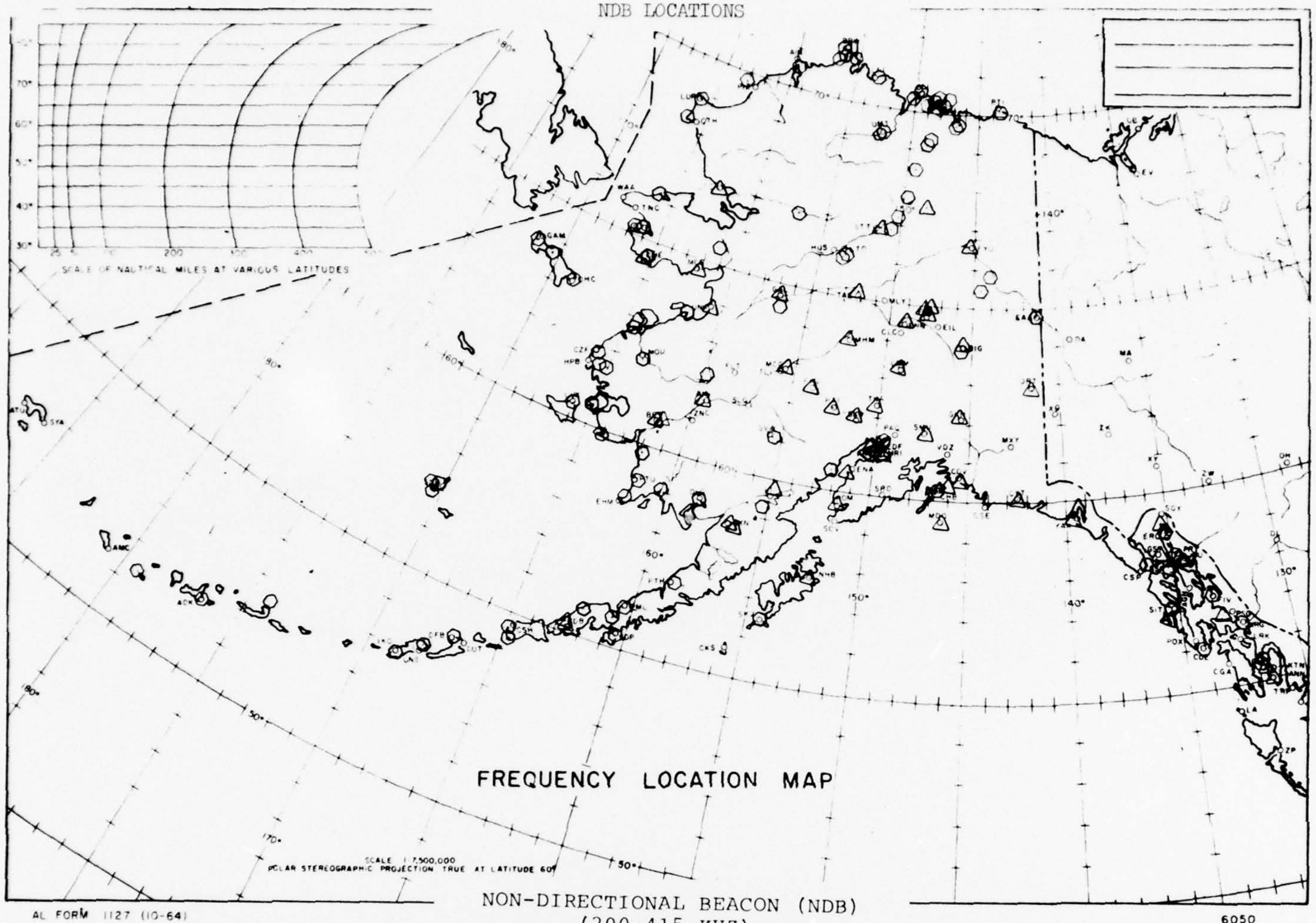


FIGURE 5
HIGH GRADIENT, 5-BAY, STACKED ANTENNA

FIGURE 6
NDB LOCATIONS



NON-DIRECTIONAL BEACON (NDB)
(200-415 KH7)
From IRAC List - 146 Total
May 1974

FAA Non-FAA

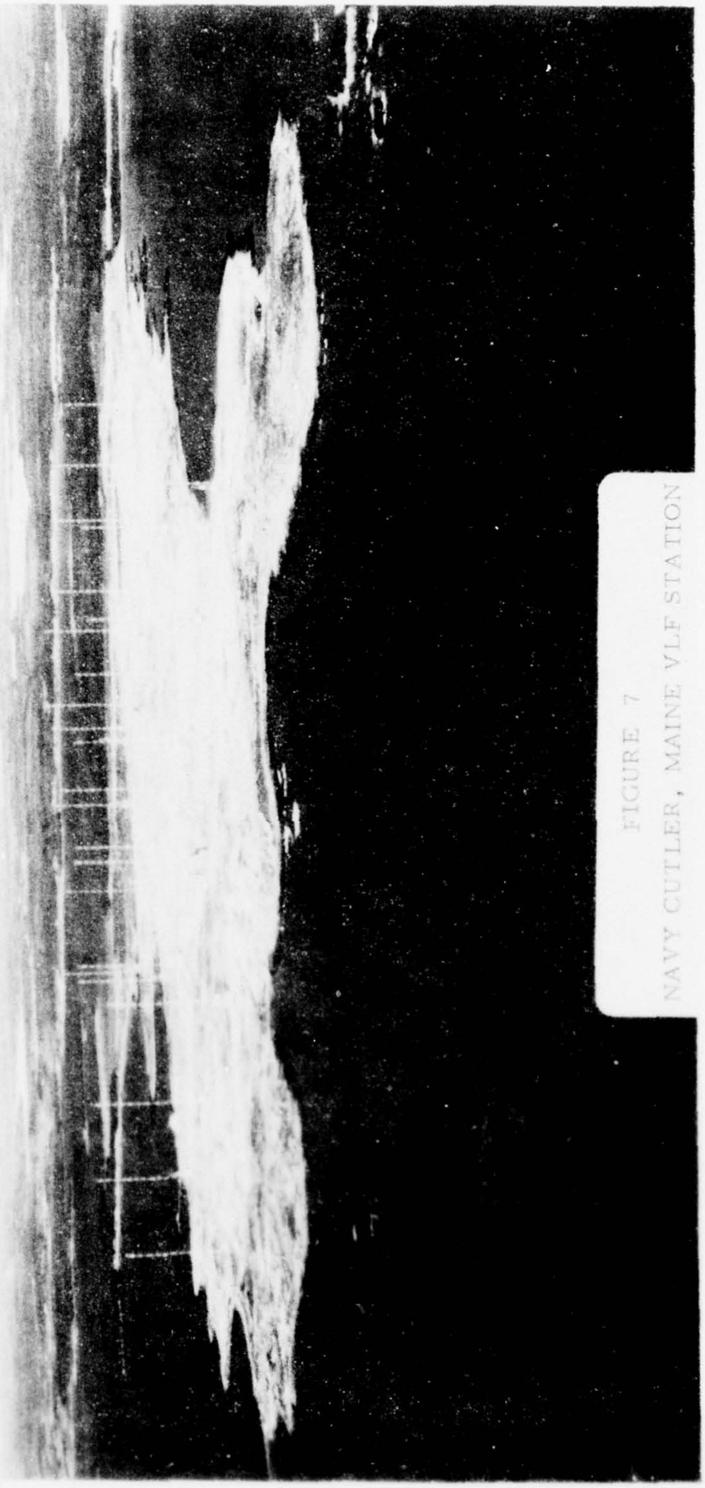


FIGURE 7
NAVY CUTLER, MAINE VLF STATION

But, the extensive deployment of these aids, the ease of implementation, and the large existing user base, especially in the general aviation community, make the retention of this system very attractive for the near term. The pipeline selection of this alternative underscores this point.

2.1.4 VERY LOW FREQUENCY (VLF) COMMUNICATION SIGNAL NAVIGATION (NAVCOM). The U. S. Navy operates a number of very low frequency (VLF) transmitters for communication with the fleet. Radiated signals are of high power and are highly phase-stable because of their control with atomic oscillators. Two companies (Global Navigation, Inc., and Communications Components Corporation) have developed airborne equipment that makes use of the communication signals for the navigation of aircraft. Each signal transmitted is at a different assigned carrier frequency. The airborne unit has nine to twelve separate receivers each permanently tuned to one of the VLF station frequencies. The computer protion of the airborne equipment uses the relative phase measurements of each selected signal to track aircraft movement from point-to-point and to present appropriate flight progress information to the pilot. Navy transmitters are located in Maine, Washington State, Maryland, Panama, Hawaii, Japan, and Australia; and are operated by Navy personnel or under Navy supervision (See Figure 7). VLF signals from the U. K. station at Rugby and a Norwegian station at Bodo are also used for navigation. All of these stations are in full operation and have been for some years. Airborne equipment is in fairly widespread use in the business aircraft and helicopter communities; manufacturers estimate that more than 800 units are presently installed. Cost of airborne units have ranged from $27,000 to $45,000.

A major consideration in the use of this method is that the Navy has not accepted a navigation mission for their VLF operations and do not operate the stations in the manner that would be most desirable for air navigation. For example, there is not always adequate warning of station shutdowns and each station is off the air for several hours at fixed intervals (e.g.; every week) for preventive maintenance.* In additon, there are technical characteristics of the VLF communication signals that have not been fully investigated which may have a bearing on their use in an airway system. Recent approvals by the FAA Flight Standards Service to

*Recent agreements with DOD have improved this situation, but communication is still the prime mission of this system.

utilize this system for IFR applications still contain many constraints and require VOR as a backup.

An alternative to establishing a DOD/FAA agreement also exists which may even be better than a stand-alone VLF NAVCOM system. This approach would be a combination of the Omega system and the USN communication station network. It would combine the navigation mission reliability inherent to the Omega system and the accuracies and continuous update inherent to the NAVCOM station due to their relatively high radiated power. This approach would, therefore, not completely obsolete the presently purchased equipment and also provide an immediate service not presently available in many remote and offshore sites.

2.1.5 OMEGA. Omega is a very low frequency (VLF) phase comparison, hyperbolic navigation system. Each Omega stations will radiate the same three frequencies (i.e.; 10.2 kHz, 13.6 kHz, and 11.3 kHz) on a time-shared non-interfering basis (See Figure 8). With VLF signal propagation characteristics, eight transmitting stations can provide a worldwide navigation capability. System Accuracy is expected to be in the order of 1 to 2 nautical miles 95 percent of the time. Presently, seven Omega stations are at full operational status (i.e.; Norway, Japan, North Dakota, Hawaii, Liberia, Argentina, and La Reunion). If arrangements can be made with the Australian Government, the eighth station will be constructed there. In the meantime, Trinidad is occupying the Australian time slot at a reduced power level. Since only three Omega stations are needed for positional fix, (two if a highly accurate clock is used), Alaskan navigation is presently possible with signals from North Dakota, Norway, Hawaii, and Japan which are currently operational. With eight stations it should be possible to receive at least five signals at any point on earth. Operation of each Omega station will be by the host nation; the U. S. Coast Guard will operate North Dakota and Hawaii. (See Figure 9)

Some airborne Omega equipment is available, but not in great quantities. Cost of airborne units for use in commercial carriers is expected to range from $12,000 to $35,000 with the degree of sophistication relative to the price. Lower cost systems below $6,000 are also becoming available. The USAF has contracted for systems of fairly low cost to be used as a replacement for Loran-A. This effort should result in considerably more activity in the development of low cost receivers. In addition, both Pan AM and TWA shall make similar purchases in the near future.

FIGURE 8

OMEGA AND VLF TRANSMITTERS

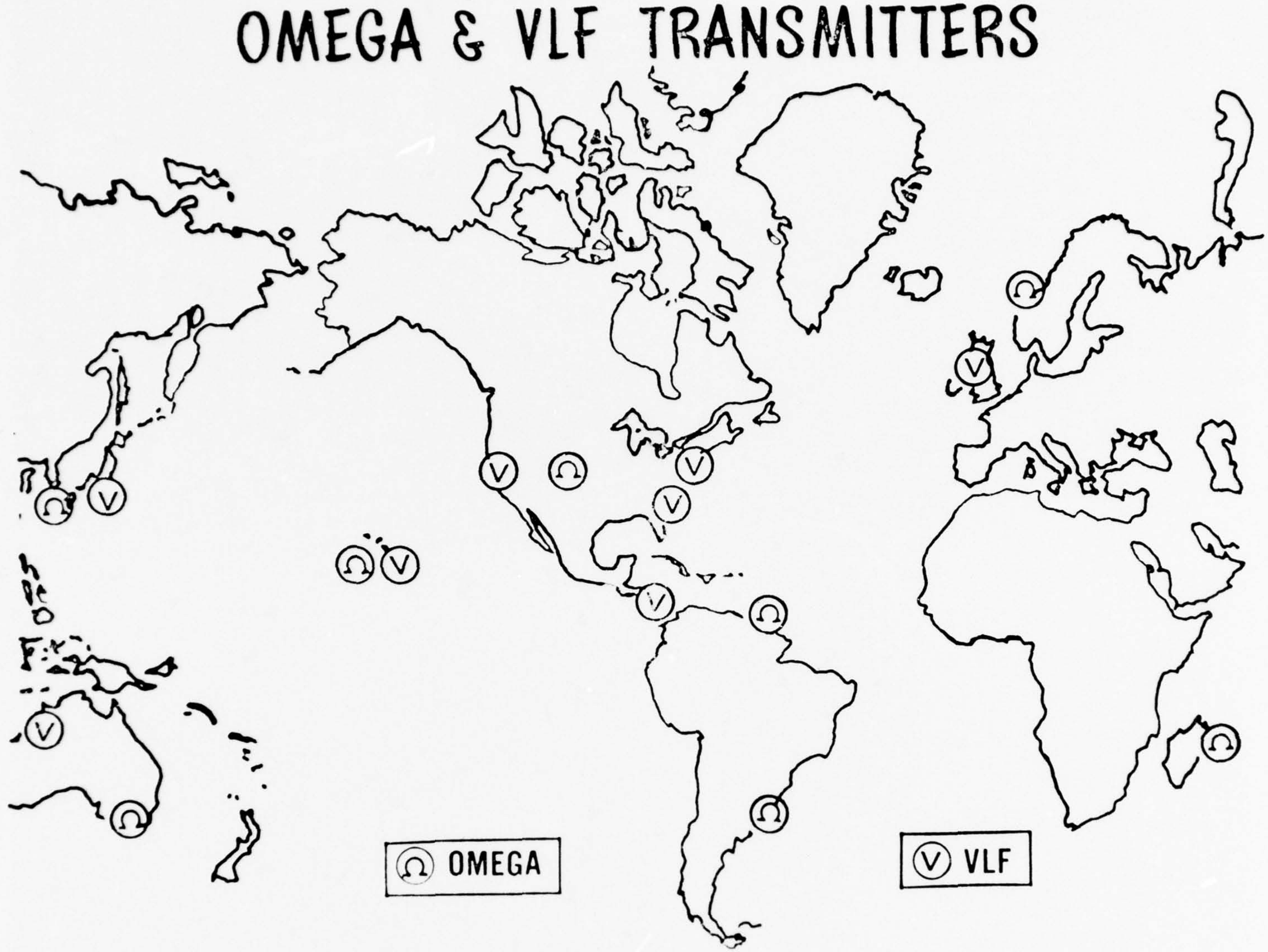


FIGURE 9
NORTH DAKOTA OMEGA
TRANSMITTER

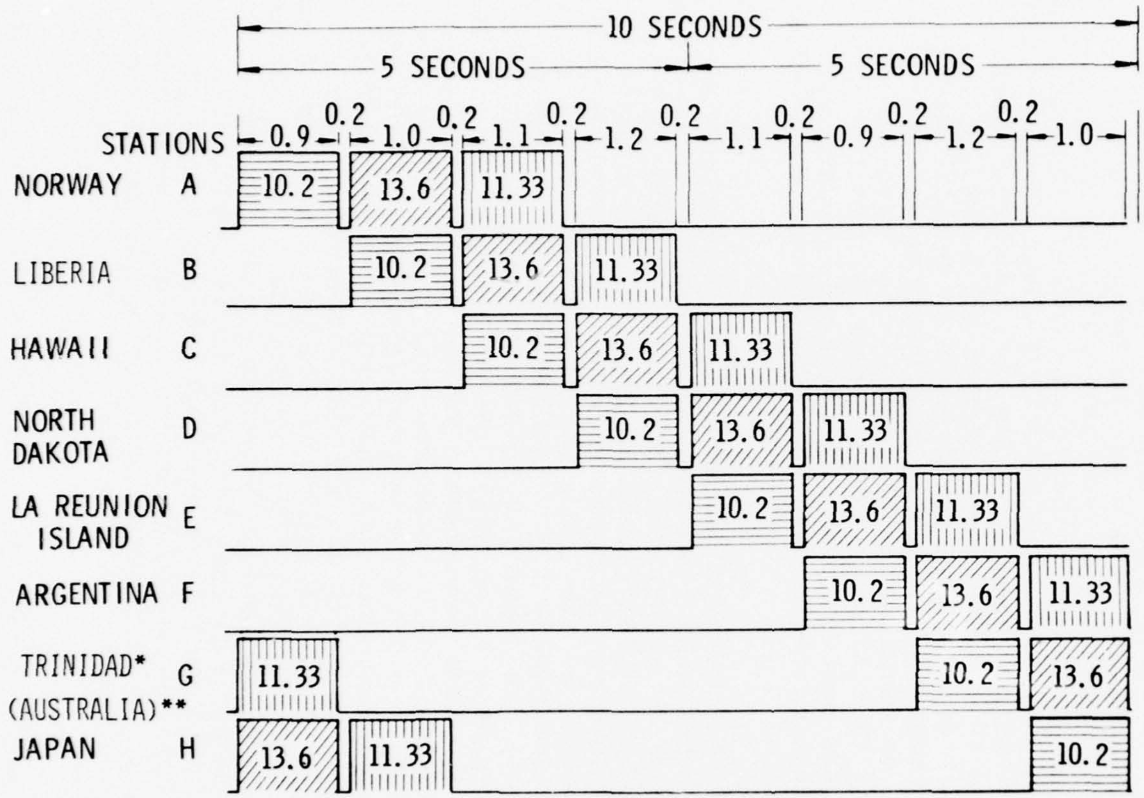
As previously stated in the NAVCOM discussion, there are a number of advantages and disadvantages to VLF systems. The significant difference between NAVCOM and Omega is that Omega is a dedicated navigation system but the radiated power is significantly less than that of the NAVCOM stations. Also, due to the multiple frequencies eminating from each Omega station the probability of reinitiating in flight is much greater for Omega using a difference frequency scheme than NAVCOM which does not have this capability.

A number of avionic evaluations are currently in process by the FAA. These include: (1) the development and evaluations of 3.4 kHz difference Omega receiver that utilizes a technique which automatically eliminates significant propagation errors* The accuracy of such a system is not as good as a normal Omega receiver but it is intended as a low cost alternative to Loran-A. (See Figure 10); (2) the evaluation of a low cost general aviation receiver built by Dynell (Mark III) (See Figure 11 and 12). High cost systems intended to replace or supplement INS installation have also been tested (Northrop AN/ARN-99) with satisfactory results. The success of the Loran-A replacement will probably dictate the extent that independent Omega will be implemented.

A technique to overcome the effects of ionosphere movements and other anomalies in a local geographic area has been proposed by using a calibration technique that is commonly known as "Differential Omega." The concept is simple and involves an Omega receiver sited on the ground near the center of the local area for which signal corrections are desired. (See Figure 13). The anticipated radius of operation will be about 150-to-200 nautical miles. With the receiver at a known site, the mathematically nominal Omega signal phase measurement values can be calculated, or they can be actually measured over a several day period. Deviations of the actual received signal phase from the nominal values expected for that site can then be automatically calculated by simple methods. When the phase deviation, or error, for each of the Omega signals received is known, the information can be broadcast to all aircraft within range of the ground site for use in the correction of the Omega signals they are also receiving. Early experiments with Differential Omega used voice messages to deliver phase corrections to the aircraft, but any operational system could use automatic transmission of the corrections. Position accuracy in order of 0.25 to 0.5 mile is expected

*This feature has been incorporated in the USAF purchase and will probably be incorporated in the commercial versions.

FIGURE 10
OMEGA FORMAT



*Trinidad station is temporary - operation will terminate September 30, 1977
**Negotiations are in progress for possible location of an Omega station in Australia.

FIGURE 10

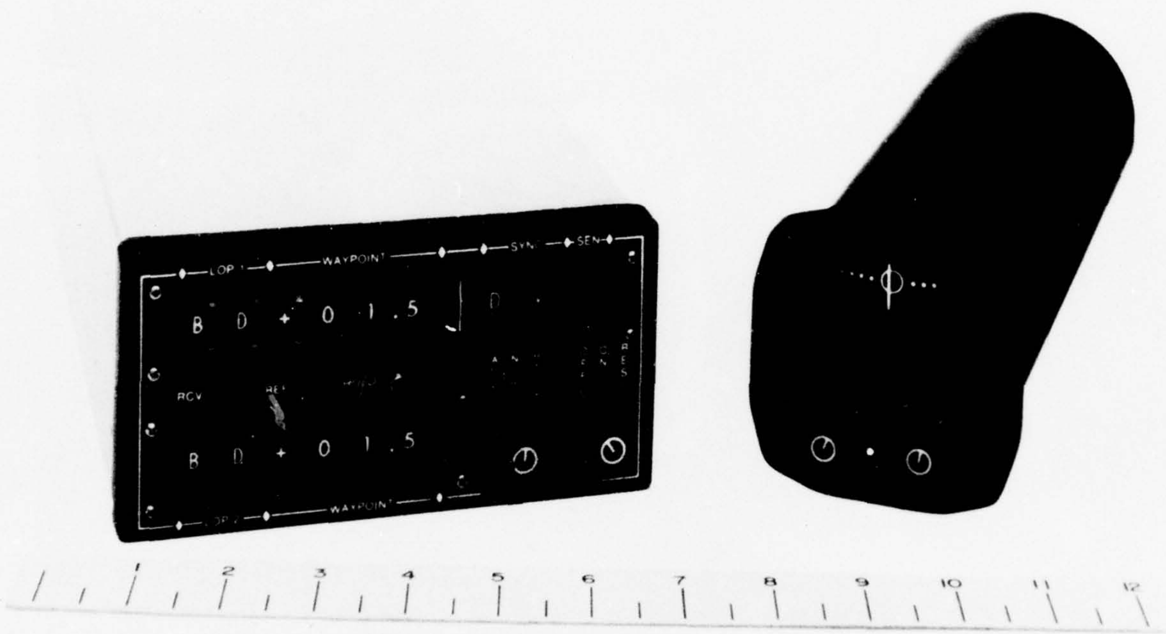


FIGURE 11
DYNELL (MK III) RECEIVER

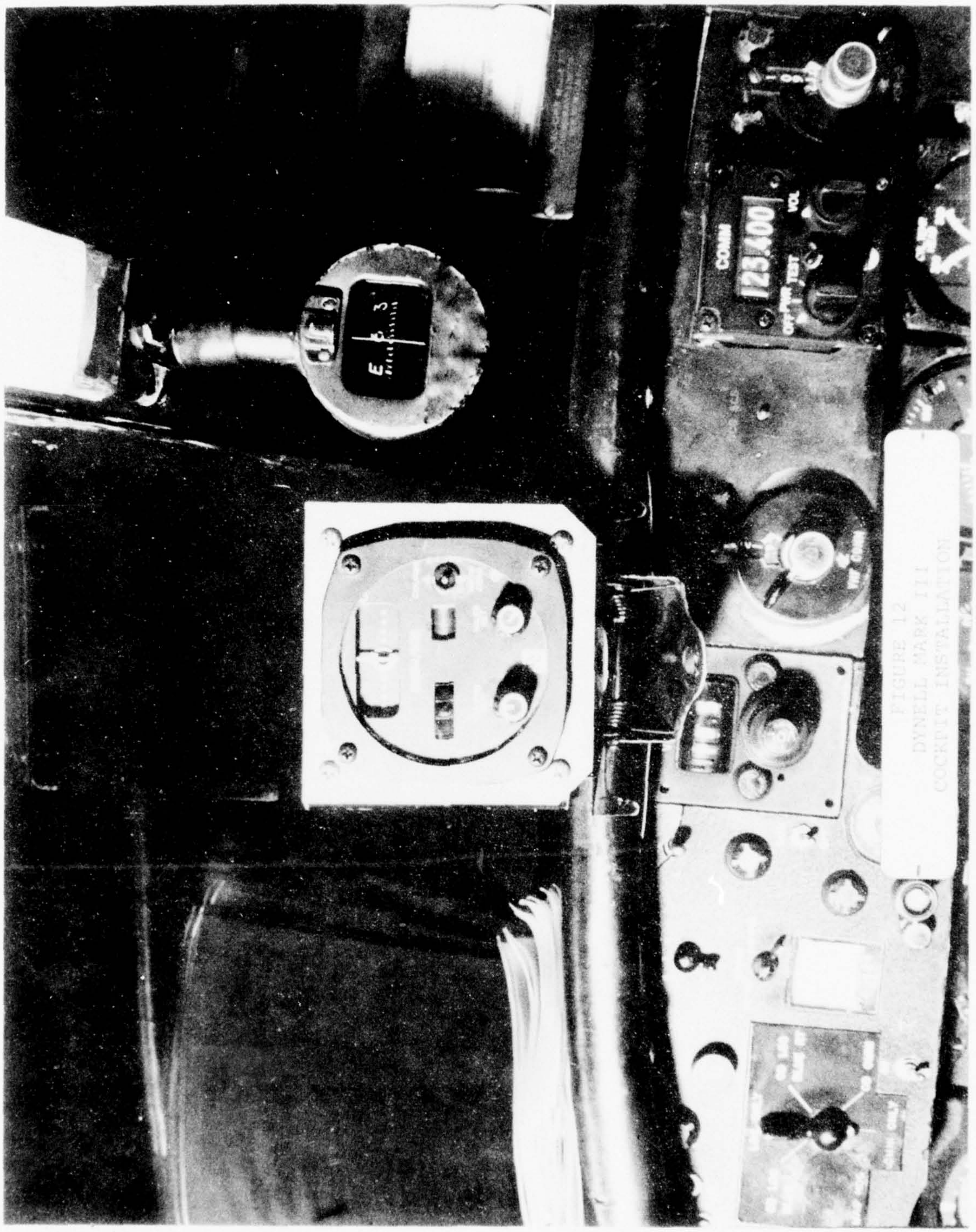


FIGURE 12
DYNELL MARK III
COCKPIT INSTALLATION

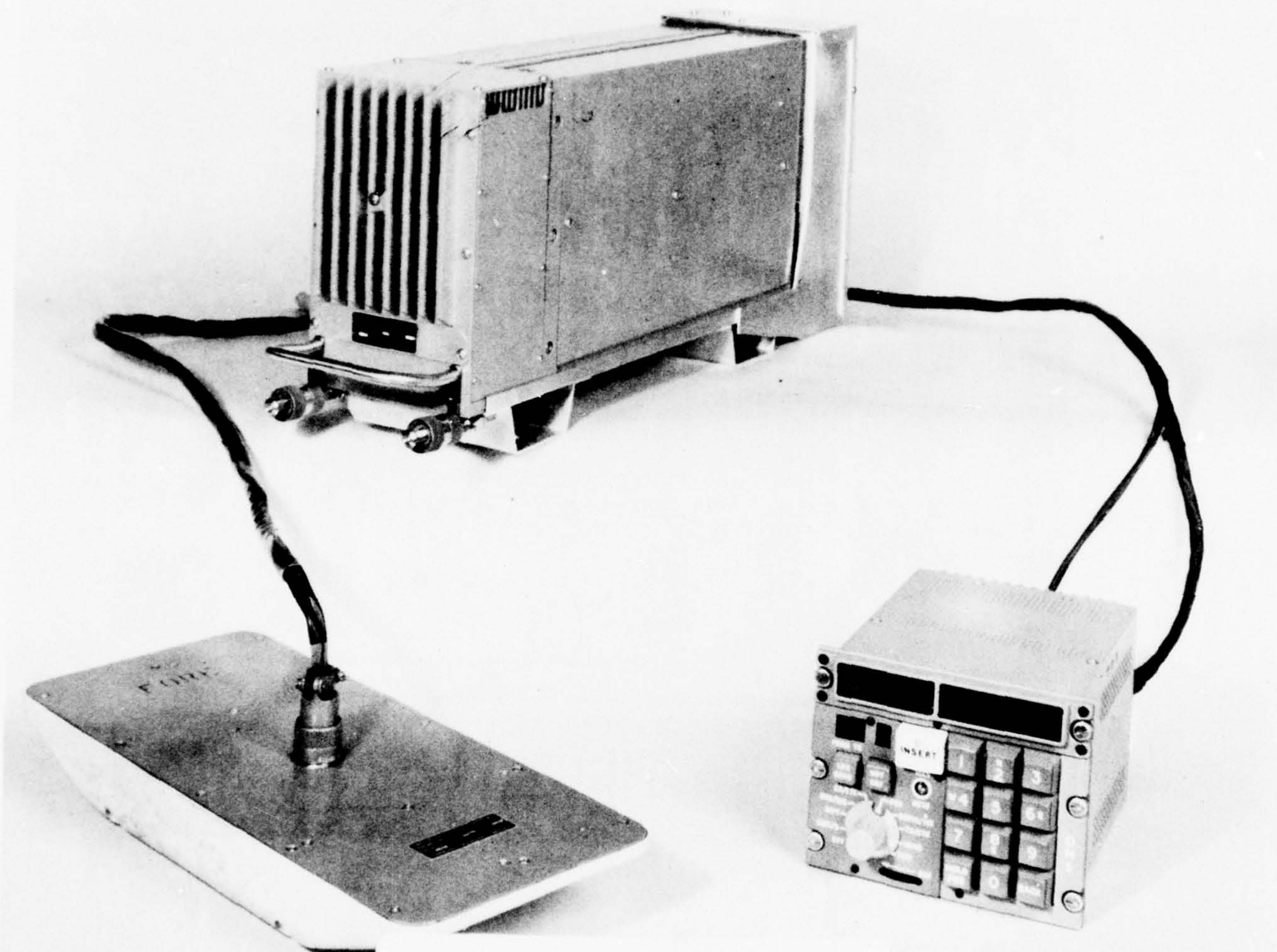


FIGURE 13
3.4 KHZ OMEGA RECEIVER SYSTEM

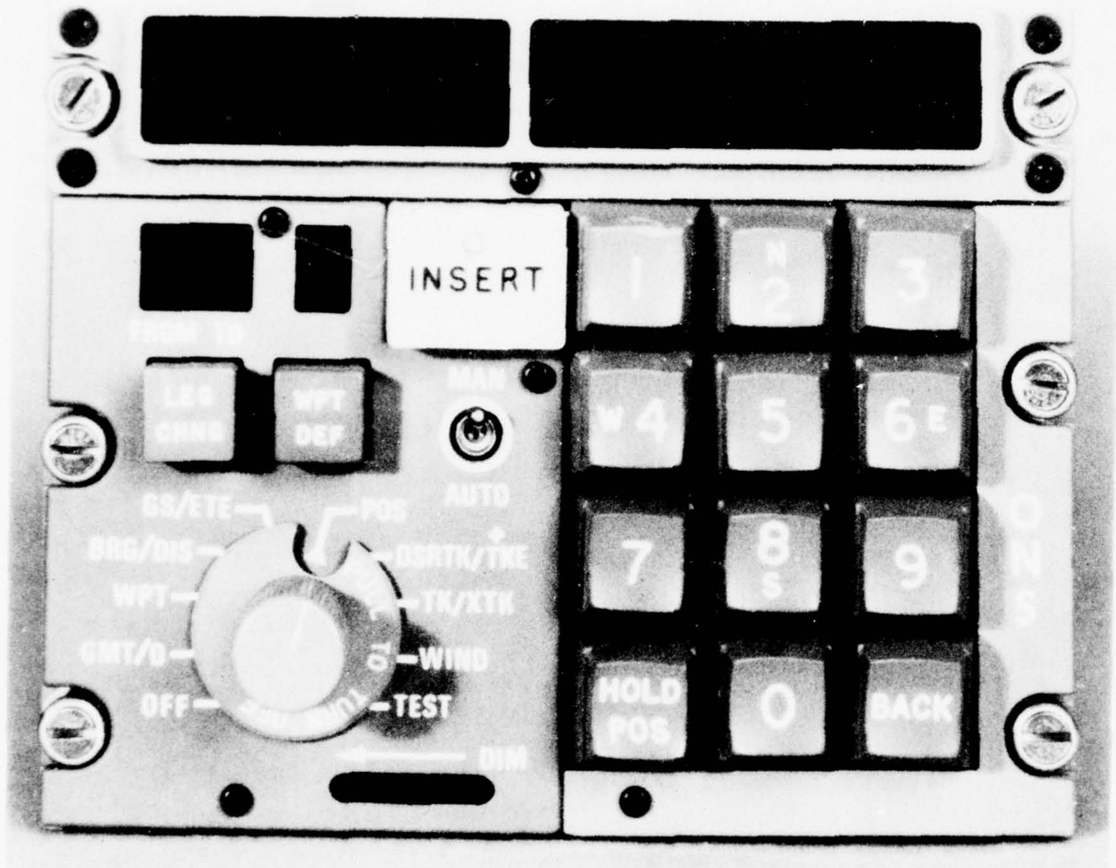


FIGURE 14
3.4 KHZ OMEGA RECEIVER CDU

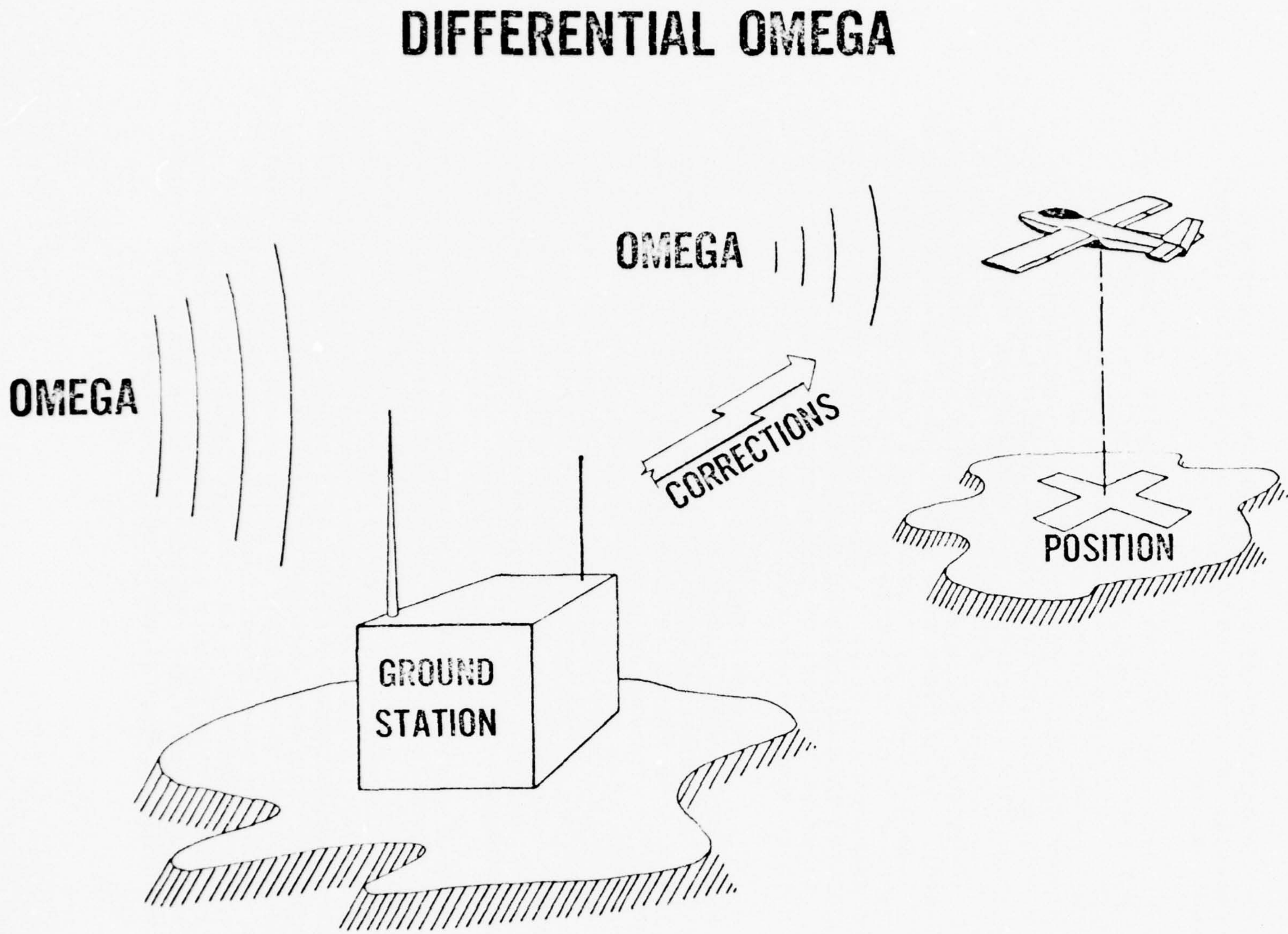


FIGURE 15
DIFFERENTIAL OMEGA

with the Differential System. These accuracies are especially important to satisfy non-precision approach requirements.

At present, the FAA has a contract with the Bendix Corporation for development of a feasibility model Differential Omega System. This equipment will help determine the ultimate utility of this technique and the most desirable operational system parameters (e.g.; correction message rate, radius of operation, transition between coverage areas of two differential stations, etc.). The Navy has tested the Differential Omega system called, "Micro-Omega," developed by the Teledyne-Hastings-Raydist Company. These tests were made on ships in the Chesapeake Bay area and accuracy figures found were in the order of 0.34 to 0.67 nautical mile to a distance of 80 miles from the correction stations. The French Government has also developed this calibration technique and an interest by the Canadian Ministry of Transportation has been evident for their remote areas similar to Alaska.

2.1.6 LORAN-C. The Loran-C navigation system is a low frequency (LF), pulsed signal, hyperbolic position fixing aid operating with a 100 kHz amplitude modulated carrier. The system is comprised of a series of "chains." Each chain consists of a master station and two or more secondary stations separated by distance of up to 600 nm. Currently, there are operational chains in the United States; one on the East Coast, one in Alaska, and one in Hawaii. A new chain is planned for the West Coast and Gulf of Mexico areas to complete the coastal confluence requirements.

A line-of-position (LOP) is determined by measuring both the difference in time of arrival of synchronized, pulsed signals from a master and secondary transmitting station, and the difference in phase of the synchronized, 100 kHz carrier within the master and secondary pulses. The transmission format consists of a group of eight pulses (nine for a master station) transmitted in sequence from all stations in a chain. A phase-coding system is used in which the phase relationship between the carrier and the pulse envelope is shifted from pulse to pulse in the group. This permits the identification of master and secondary signals and results in cancellation of skywave contamination from an early pulse in the group.

Line-of-position determination is performed in the receiver in two steps. First a coarse determination of position is obtained by establishing a sampling point on the envelope of each pulse and measuring the time difference between the sampling points. This measurement is called the envelope reading. Secondly, a fine indication of position is obtained by measuring the difference in phase of the 100 kHz signals at the sampling point. This is called the cycle reading. The two measurements are made in separate channels of the receiver and final time difference value is determined by adding the fine cycle reading to the course envelope reading.

As in all phase systems, the cycle measurement is ambiguous in LOP determination. At the transmission frequency of 100 kHz, one cycle of rf energy represents 10 microseconds; this cyclic ambiguity results in baseline land widths of approximately 0.8 nm. However, this ambiguity may be resolved automatically by the receiver as long as the envelope reading is correct within ± 5 microseconds. The user does not have to count lanes or know his position within some prescribed tolerance. The primary cause of inaccuracies in this envelope measurement is due to the fact that different frequencies propagate at slightly different speeds (phase velocity), resulting in a phase shift of the pulse envelope with respect to the 100 kHz carrier. This anomaly is known as envelope-to-cycle discrepancy (ECD).

Because Loran-C is a pulsed system, the skywave signal is separated in time from the groundwave. It can be shown that the first-hop skywave propagation time always exceeds the groundwave propagation time by a minimum of approximately 30 microseconds. Thus, by time sampling near the beginning of the received pulse, the Loran-C system is able to resolve the ground energy from the delayed skywave allowing navigation solely on the stable uncontaminated groundwave out to distances of approximately 1000 nm.

The repeatable accuracy and groundwave coverage of the Loran-C system is, therefore, not subject to diurnal and seasonal fluctuations resulting from changes in the earth's ionosphere; rather, the accuracy and coverage are determined by the instrumentation accuracies, system geometry, transmitter power, and ambient noise levels, ground conductivity, and noise interference.

Loran-C, along with the ambiguity, atmospheric noise and solar disruption problems previously noted for VLF systems is also highly sensitive to single station failure. When stations fail, as they occasionally do, all aircraft using Loran-C within an extensive area may be suddenly left without navigation. Therefore, for use as a primary navigation, redundant transmitters and antenna fields may be required. Since all stations transmit on the same frequency, channel interference may be a problem if a significant number of redundant stations are required. In addition, sudden station failure detection, especially during the approach phases, may increase avionic complexity and cost. Also to be considered is the fact that operation of Loran in the Artic Regions may be difficult due to the peculiar magnetic/ionospheric conditions found in that region. Another problem arises from the fact that the frequency used is not internationally allocated for this mission, neither are guard bands stipulated to protect the 100 kHz signals from side bands from adjacent frequencies. This requires filtering hardware specifically tuned for regional use.

2.1.7 GLOBAL POSITIONING SYSTEM (GPS). This system, also known as NAVSTAR, is presently being developed by DOD as the eventual all purpose navigation system for the great majority of its missions. The present operational target date is 1984. It is capable of real time three dimensional positioning information accurate to within 10 meters. In its full operational mode, 24 satellites will orbit in three 10,000 nm high subsynchronous planes resulting in eight (8) satellites per ring. (12 hour circular orbits, inclined 60 to 70 degrees.)

Phase I will consist of 6 satellites. The first will be developed by the Naval Research Lab (NRL) and will be identified as NTS-2, a Navigation Technology Satellite. It is scheduled for launch by late 1976 or early 1977. The remaining (5) called Navigational Development Satellites (NDS-1 to 5) will be GPS prototypes. These are scheduled to be launched beginning in 1977. This configuration of six (6) will allow four (4) satellites to be in view of the continental U. S. for at least four (4) hours per day. NTS-2 differs in that it will also allow testing of the "L" band frequencies selected for this system.

Two (2) different frequencies using pseudo random noise are being utilized with the higher frequency containing the navigation data. The other frequency will be used to detect and minimize the effect of electromagnetic disturbances. The MTBF of the operational satellite is

estimated to be approximately five (5) years requiring an annual replacement rate of four (4) to five (5) over a 30-year period. In addition to the satellites, the system requires a ground complex consisting of 4 monitors and a master control station. The master station, using the data supplied by the monitors, will determine satellite ephemerides, ionospheric propagation and clock bias errors. This data is relayed back to the satellites for subsequent use by the airborne receivers.

Phase II will result in increasing the number of satellites to at least nine (9) and possibly eleven (11). This will allow continuous 2D and periodic 3D capability. This phase is scheduled for 1982 and would be the first time that the system will be useable for the civil sector. Full operational capability of 24 satellites is then scheduled for 1985.

At present, six (6) classes of user equipments are being developed ranging from a continuous tracking receiver having four (4) channels for simultaneously processing four (4) satellites (Hi-dynamic) to a sequential receiver having one or more channels (Low-dynamic). The Low-dynamic receiver group includes the low cost Class C version which is intended to replace present TACAN equipments and be the basis of the eventual civil unit. Current estimates for this class ranges from $26,000 to $15,000, although some sources feel that a $2,500 model would eventually be available making it competitive to a present VOR/DME package.

Obviously, a worldwide system in this frequency band would be an ideal solution for our future navigation needs. Since the user operates in a passive mode, the system cannot be saturated. Its accuracy and redundancy is also impressive. It would also allow a user to equip only to the level necessary, starting from a simple 2D single channel arrangement to a multi-channel 3D or 4D configuration for terminal and approach applications. Unfortunately, the price of the low cost version necessary to co-exist with military anti-jamming requirements poses serious questions. In addition, the time frame for initial operational use does not meet the Alaskan near term requirements. The large cost of such a scenario and the possibility of certain elements of the community using alternative techniques independently, due to necessity, are good reasons for a cautious approach in recommending this system.

Of course, this concept could be eventually selected to replace the VORTAC system for all the U. S. as a long term solution. But, with regard to the Alaskan needs during the period that VORTAC remains prime in the continental U. S., this alternative does not seem valid. Although, not immediately impacting on the Alaskan problem, a unilateral action by DOD to use GPS as the prime NAVAID in the 1980s could reduce the selection of TACAN from both a near and far term aspect.

2.2 <u>HYBRID SOLUTIONS</u>. A number of hybrid or combined systems are presented in the following discussion. These include NDB/DME, Omega/Differential Omega/DME, and RNAV using VOR/DME inputs. As explained in the previous discussion of basic navigation systems, each technique has unique advantages and disadvantages. Therefore, a combination of systems is attractive due to three basic factors:

A. From a safety/reliability standpoint, two independent signals have an obvious safety advantage. This rationale applies to both ground and airborne equipments.

B. VLF/LF systems which are excellent from a signal coverage standpoint have signal reliability problems due to propagation anomalies, solar disturbances, and atmospheric noise. Therefore, to achieve the signal availability performace of the present VORTAC system (necessary for IFR operation) some other technique (frequency band) is a distinct possibility.

C. The evolution of a new navigation system is always painful since a large existing equipment investment, both ground and airborne, must be amortized. This results in dual systems being operative over significant periods of time until avionics retrofit is completed. Therefore, if some sort of logical evolution can be accomplished by using and retaining common equipments, such as DME, this transition could be greatly simplified.

Also, more specific than the above factors, the addition of the range dimension to a basic bearing system such as NDB and VOR allows a significant improvement in determining a minimum approach altitude (MDA) for an airport. This reduction in ceiling and visibility requirements is directly related to the ability to use final approach fix (FAF) as specified in the TERPS Handbook.

2.2.1 NDB/DME. As stated in the previous discussion, a large number of NDBs are presently deployed in Alaska. In addition, the pipeline interests have implemented additional NDBs for their construction camps; co-located with DMEs. A number of Alaskan based air carriers have also supplemented the FAA system with NDBs.

The advantages and disadvantages of each of these NAVAIDs have also been previously detailed. Therefore, the marriage and implementation of this combination is not surprising.

In summary, NDBs are commonly used in Alaska and, therefore, avionic availability and implementation is not a problem. Although DME avionics are not in the majority of aircraft, their availability and cost is reasonable. Installing the ground facility is also less of a problem than a VOR which also enjoys a wide avionic advantage. On the minus side of this approach is the fact that the signal reliability is not especially good due to ground conductivity and weather problems. Bearing accuracy may also fluctuate widely due to terrain problems. Therefore, co-locating a DME with the NDB not only adds the range (distance) dimension to the system but also allows a fail soft position. The "L" band frequency is less susceptible to weather factors and the cost of solid-state DMEs is also quite reasonable. Siting preparation in addition to that necessary for the NDB are not significant.

It is also conceivable that the NDB could also be used in the future as a communications facility for such information as the corrections necessary for Differential Omega and alarms to warn pilots of the extent and predicted duration of signal anomalies caused by such factors as solar disturbances (SIDs). Also, the DME ground stations could be the basis for a future system, supportive of GPS/NAVSTAR.

2.2.2 OMEGA/DIFFERENTIAL OMEGA/DME. This system could be considered both a near term as well as a long term solution. Four Omega stations are now available for use across Alaska. Therefore, its immediate use is possible but, unfortunately, not practical. The presently available receivers are very expensive ($12K to$25K) and are intended as a replacement for Loran-A and/or costly INS equipment. But, the development of low cost receivers, such as the Dynell Mark III, must occur rapidly. It is foreseen that receivers for under $5,000 are possible in the near future, but the acceptance by the GA and air taxi community will be critical. For this reason, Omega as the near term solution (the next 2-to-5 years) is questionable. Except for the NDB/DME and VORTAC solutions, this is true of all other alternatives.

To make this alternative more attractive, Differential Omega is the next logical step in the development. As explained previously, not only is the basic accuracy improved, but it also allows the capability of minimizing the effects of atmospheric and solar disturbances. The ideal situation would be to develop moderate to high cost avionics with this capability as soon as basic Omega has proved feasible and the necessity for increased accuracy and reliability for non-precision approaches becomes obvious. Since any new VLF-LF system will require a network of monitors, dual use of such facilities would be an economical method of demonstrating this capability. This would require the FAA to specify Differential Omega as a possible long term solution in order that avionics manufacturers proceed in this manner. In addition, low cost receivers which can be manually updated by the pilot using corrections via a voice data link channel from an ATC facility could also be incorporated in the near term. Although this approach entails a high workload, its application in low density areas could prove practical; especially at those hundreds of airstrips which cannot qualify for any type NAVAID. It is also envisioned that the ¼ to ½ nm accuracy achievable through this technique would also aid low altitude operations requiring passage through mountain passes. It should also be noted that for short stage lenth operations, calibration of the basic Omega receiver before takeoff would probably allow accuracies much better than the long haul 1 to 2 nm presently measured; thereby making the Differential Omega technique necessary only for those unique situations where stage lengths of more than 150 nm are necessary and/or atmospheric anomalies occur.

2.2.3 AREA NAVIGATION. Most RNAV avionics presently being manufactured use VOR and DME inputs. None, to our knowledge, use NDBs as bearing inputs. Only a few expensive models have a range/range capability. By using RNAV, the large number of VORTAC stations required for a conventional radial airway route structure could be minimized. Unfortunately, the rather rugged terrain would limit this advantage only to the high altitude structure due to line-of-sight limitations. This approach, with VORTACs at high density terminals, should be adequate for high altitude air carrier operations.

It should be noted that Omega is a natural RNAV system which contains the ability to fly between a number of preselected "waypoints." Differential Omega will improve the accuracy of basic Omega to allow non-precision approaches and possibly allow the development of lower cost avionics.

It is also recognized that INS has an RNAV capability although the inherent drift of these systems limit their application on airways. Manual updates have been developed but are considered too cumbersome from a flight technical error and workload aspect. An Omega (low cost) update capability is a possible solution to this problem as well corrections from a simple conventional VORTAC RNAV (or vice versa) for an improved dead reckoning capability between widely separated VORTACs. Obviously, these solutions would only be applicable to the air carriers or by jets which want to make maximum use of their already installed INS or Doppler capability.

Therefore, an RNAV approach would obviously minimize the number of VORTACs required for high altitude coverage. It could also improve the effective service volume of the existing VORTACs. But, as a long term solution for all classes of users, the inherent disadvantages of the ground VORTAC system still exist.

2.3.0 COMMUNICATIONS AND SURVEILLANCE. In any study concerning NAVAIDs requirements, it is essential that communications surveillance related to establishment of NAVAIDs also be given proper consideration. In the contiguous States, establishing communications (as related to NAVAIDs) is, typically, not a problem. In the Alaskan Region, however, establishing communications to serve NAVAID facilities is, in many cases, difficult and expensive to achieve. The reasons for this are many and varied but result mainly from the topographical situation and the relative paucity of existing telephonic exchange and toll services due to population distribution.

Various combinations of VHF lines, microwave links, RCA satellite communications, and landlines provide existing communication between NAVAID facilities and associated control points. These links presently serve to (1) enable voice communication between the NAVAID and the remote control point, (2) provide a go-no/go status signal of the facility, (3) enable remote control of the facility to disseminate weather information, etc., (5) assist technicians in limited testing of the facility from the control point and (6) provide a means to feed the audio from a VHF receiver (when facility is so equipped) to the control point. Other communication link requirements, not directly related to NAVAIDs, include weather data transmission from remote sites to a control weather facility and air traffic control communications. The coordinated utilization of existing and future communication systems is very desirable for obvious economic reasons reasons. Co-location of remote weather sensors and NAVAIDs facilities is an example of this coordinated utilization.

The present status of communications relative to NAVAIDs requirements in the Alaskan Region is as follows:

A. All but one of the FAA-owned VOR/VORTAC facilities in the Alaskan Region has communications between the NAVAID facility and an associated control point. The exception is the Moses Point (MOS) VOR facility. There is a diversity of communication links used in effecting these links.

B. The Alaskan Region is in continuous contact with RCA Alaska in connection with the on-going assimilation of various existing links (White Alice, etc.) into the RCA Satellite System.

C. The region is very much aware of the economic benefits derivable from coordinated utilization of available and future communication links with other functions such as weather data transmission and ATC communications for example.

D. Most proposed VOR/VORTAC facilities will be at locations having either civil or military exchange and/ or toll service available. Also, proposed facilities are to be located proximate to an airport also served by an NDB facility.

In summary, the Alaskan Region is keeping abreast of the on-going RCA satellite system expansion and is effecting coordinated utilization of existing and planned communication links relative to navigation support.

Present R&D developmental efforts of a 2nd generation solid-state VORTAC will include an effort to develop an automatic dial-up capability for transmitting maintenance and monitor data to a central maintenance center. It is expected that a voice grade channel will be required to implement this remote maintenance monitor system. The agency is now in the process of evaluating its communications requirements. The resulting system will optimize the common usage of all modes when possible. For this reason this report will not expand on this factor.

In addition to the above discussed communications requirements, a flight following service capability may be instituted. In this event, air-ground/ground-air (via NDB facilities possibly) communication links may be required. Although the interdependence of navigation, communications and surveillance is well recognized, the requirements cannot necessarily be developed in parallel. Therefore, those decisions made in the navigation area will be the seed to

to develop firm concepts in these and other areas.

2.4.0 ALASKAN FLIGHT TESTS.

2.4.1 GENERAL. A series of flight tests have been performed by NAFEC to evaluate the potential of Omega as the long term navigation aid for the Alaskan/Aleutian airspace. Tests of Loran-C were also performed to determine that system's performance and coverage. A total of three series of flights were performed; once in January 1975, May 1975, and September 1975.

The January series were cancelled upon arrival in Anchorage due to an unscheduled shutoff of the Hawaii Omega ground station. This station was not in its full operational mode at that time and a ground antenna modification was performed without general notification. Since that time, Hawaii has been formally classified as operational and future scheduled down times will be coordinated with the other stations and reported well in advance.

A DC-6B aircraft, N46, was instrumented for the Alaskan flights in January 1975. This instrumentation was then transferred to the Convair 880 (N42) prior to May 1975 for rescheduled tests. Both installations were designed to allow the pilot to navigate by Dynell Mark III Omega information, while available aircraft navigation systems were relied upon for comparison data. Both installations relied upon an E-plane antenna for reception of Omega signals. The Dynell Mark III will be sold for approximately $6,000 and is designed for general aviation use at maximum speeds of 400 knots.

In both installations, the equipment under test, the Dynell Mark III Omega Receiver, was interfaced with an Incredata magnetic tape recorder for data collection. Extended cabling allowed the indicator unit to be placed at pilot's position for navigation purposes.

An additional rack was installed on the CV-880 consisting of a Tracon 599R Omega receiver, quartz frequency standard, antenna coupler and brush analog recorder. This monitor provided continuous analog recordings of the Omega signals received by the Dynell Mark III equipment and partial recordings of station pair comparisons obtained from the Tracon 599R receiver. All data collected was synchronized to an onboard time code generator. A continuous flight log was maintained by voice recorder.

Position reference data was obtained by photographing the aircraft LTN51 Inertial System Display at a one minute rate during all flight tests. Position reference and conventional NAVAIDs coverage was also recorded continuously with the flight inspection console analog recorder. Synchronization and programming are fairly simple, requiring some basic computation of the Omega coordinates at selected station pairs for origin and destination positions.

A second low cost Omega set, the Dynell Mark IIIA, was also operated during the Alaskan flights. This equipment is an improved model including constant display of present positioning Omega coordinates, circuitry to perform coordinate difference computations internally and two waypoint storage. After manual synchronization, only insertion of destination in Omega coordinates for station pairs selected and length of trip in nautical miles are required.

2.4.2 RESULTS. In general, reception of signals from Omega stations in Norway, Hawaii, North Dakota, and Japan were of high quality during VFR conditions on all flights in Alaskan airspace. The Norwegian Station was unusable from a line through White Horse, Canada, west, to another line passing south of the Yakatut-Sitka area along the Pacific coast. Station pairs AD and AC were processed on all flights for using the Dynell Mark III. Alternate pairs CH and CD were considered but the reliability of Japan's station had not yet been established. Later, the CH and CD pairs were programmed into the Dynell Mark IIIA and good results were achieved for the final flight. As expected, flights through snow showers and dense clouds were characterized by high noise levels and imparied signal reception. The effect on Omega navigation depended upon the density of the snow or clouds and aircraft speed. These effects, characteristic of operation with E-plane antennas, are expected to be less noticeable when more representative types of general aviation aircraft are flown in Alaska; at lower speeds and altitudes.

The Dynell Mark III and Mark IIIA Omega sets performed well considering the severity of the demand. Although some trip initializations were performed enroute (transfer or origin) over waypoints, the majority of test flights retained Anchorage as origin.

This resulted in long duration legs with many waypoint calibrations enroute. The manual waypoint calibrations are a source of accumulative error build-up due to human factors. Errors in the distance along track appeared to be more likely to be long than short of actual distance and more likely to occur than errors in course deviation

indication. There were no failures in the Omega equipment with the exception of the Experimental Active Blade which otherwise would have supplied signals for Dynell Mark IIIA operation. A measure of end point accuracy was obtained from observations recorded during test flights in various signal conditions.

The Dynell Omega equipment, though manually synchronized and programmed, is relatively simple to operate. Pre-flight planning is necessary but not excessively time consuming. It appeared to be adequate as a VFR ONLY supplemental enroute system. It is quite possible that signal interference due to cloud and snow shower penetration would be decreased if flown at lower airspeeds used by light aircraft using an E-plane antenna. However, the weak link in low cost Omega avionics navigation remains; the antenna. E-plane plates or noise cancelling units may aid in solving this problem.

Omega signal reception from Norway, Hawaii, and North Dakota provides adequate coverage of Alaska with respect to geometry. For all practical purposes, the worldwide Omega system is complete in Alaska. There are several station pairs available for primary and alternate use. Station outages remain a problem. Signals received during all test flights were quite useable, except when penetrating dense clouds, or when a station outage occurred. The test series flown can only be considered a minimal probe in assessing the characteristics and reliability of Omega signals. Repeated monitoring at various points in Alaska would provide more thorough and complete information regarding Omega propagation and the natural phenomena which affect it.

The flight in May also carried an ADL-81 Loran-C receiver, manufactured by Decca Ltd. which malfunctioned due to installation problems.

The Convair 880 again flew a series of flights in Alaska during the week of September 15, 1975. This flight repeated the Loran-C tests and also evaluated the performance of an Anecom ONS-201 Omega receiver. This equipment is designed to be a direct replacement for INS installations and will be marketed in a price range of $12,000 to $25,000. The ADL-81 is not configured for aircraft operations. Equipments presently being developed will be competitively priced.

During these tests, it was observed that the Omega system operation was satisfactory in all parts of Alaska. Initial indications are that its accuracy was within the range normally expected. A detailed analysis is presently in process and is the subject of a subsequent report to be issued by NAFEC.

As for Loran-C, observations during these tests indicated that significant areas of Alaska do not have adequate coverage. Satisfactory results were obtained where signals were available. Initial indications are that at least two (2) additional stations would be required for complete Alaskan coverage with adequate geometry.

In short, it can be concluded that at least four (4) Omega station signals are presently available in all parts of Alaska. A fifth station (Argentina) is already in operation and may also furnish signals; although this has not been confirmed. Present Loran-C coverage is not adequate and is deficient from both a signal coverage and geometry aspect. This would require additional stations to be established in the rather unique Alaskan environment.

3.0 CONCLUSIONS.

3.1 VOR should not be chosen to meet the long term or mid-range needs of navigation in Alaska if Omega proves to be a feasible supplement system. Limitations imposed by the terrain and the cost of installation and maintenance are presently overriding factors. Although new solid-state models of VOR are presently being developed and new antennas evaluated, a substantial number of sites would still be required. A minor number of VORTACs could be implemented to provide a suitable high altitude RNAV structure and suitable IFR service to critical terminal areas for air carrier operations for the near future.

3.2 Loran-C is not presently suitable for near term air-carft navigation in the domestic air traffic environment based on the previously stated factors. Plans for its long term use as a VORTAC/NDB/DME replacement should be carefully weighed against a satellite option such as the Global Positioning System (GPS/NAVSTAR).

3.3 Omega is considered to be a viable long term supplemental solution since:

a) Omega has provided a navigation capability over the entire Alaska area since the end of 1975, allowing its immediate use as avionics become available.

b) Omega accuracy and repeatability could be improved use of local area differential corrections which would allow non-precision operations in isolated areas.

c) Co-location of DMEs at airports for the near term solution with NDBs, VOR/DME, or TACAN will allow for fail soft terminal operations when used in conjunction with Omega.

3.4 Although most of the same disadvantages apply to the combination of NDB/DME facilities as for the VORTAC approach, the existing extensive ground network, the large user investment in avionics, and the tendency of users to continue their operation (the pipeline for example), forces strong consideration to upgrade this technique to satisfy the near term requirements.

3.5 If so decided, a gradual transition could be made from NDB/DME and VORTAC system to Omega, later supplemented by Differential Omega, as airborne and ground units are developed, evaluated, and new aircraft enter and replace existing inventory. This gradual shift in systems would probably be more acceptable to the large user community than would a VOR or TACAN approach with a limited service area and eventual replacement by GPS/NAVSTAR or Loran-C.

3.6 Recognizing the fact that TACAN is an ideal solution for oil platform installations, there is a possibility that some support may be required from the FAA as a gap filler. Therefore, the co-location of NDBs with a small TACAN instead of only a DME might be advisable if user demand warrants this exception. It should be pointed out that TACAN avionics is expensive and DOD is considering phasing this system out with the advent of GPS. In addition, although siting is easier, its long term feasibility is questioned due to the line-of-sight limitations as well as the considerable O&M costs.

4.0 RECOMMENDATIONS.

4.1 Proceed with the installation of enough NDBs and DME facilities to meet the most immediate and pressing navigation needs in Alaska. Takeover of some existing privately-owned NDBs may be advisable.

4.2 Consider a transition to Omega/Differential Omega early in the 1980 period if that system is shown to have merit. GPS avionic development should be closely monitored from a low cost user aspect.

4.3 Install VORTACs to support the high altitude RNAV, critical terminal area and international air carrier requirements after development of solid-state modular VORTAC with automated remoting.

4.4 The advantages of TACAN for oil drilling platforms is obvious as a near term solution. But, this activity is not likely to be a pervasive requirement for the next five years due to offshore leasing delays. If necessary, a gap filler program should be approved if other requirements are indicated.

APPENDIX I

GENERAL COST ANALYSIS

1.0 GROUND FACILITIES. The following is a general comparison of the relative costs between logical contenders for the Alaskan Region navigation system. This will include VORTAC, VOR/DME, TACAN, NDB/DME, NDB/TACAN, and NDB only.

The total implementation costs for each alternative is obviously dependent upon the number of sites required. The reliability, automated monitor/maintenance capability, unique siting requirements, and power requirements will also have a significant bearing on overall costs. Therefore, the total costs for each alternative are not compiled since the number of sites necessary is very sensitive to the estimated requirements. Normal conus criteria for a site to qualify for a certain NAVAID is obviously not applicable to the Alaskan situation.

In this report no attempt is made to specify how many sites should be upgraded, but only to rank the ones which we consider the most deserving sites (See Volume II). The level of available funding, the latest requirements, and the alternative chosen will then dictate the number of sites. In addition, as recommended in this report, a number of the different alternatives may be selected for the near term solution predicated on factors not presently established. The large number of possible combinations would tend to detract for this exercise.

For this reason, only the cost of a single typical configuration of each alternative for the near term solution is presented in Table I-1. In addition, Table I-2 highlights the large differences in construction costs between a standard (average) installation of VOR/DME and NDB in the contiguous U. S. as compared to Alaska. It is our understanding that this 3-to-4 time increase is typical for any type of construction in this region. Freight and construction material costs are also understood to be greater. It should be noted that these costs do not reflect the sizable reduction in equipment costs and O&M which will result from the 2nd generation VORTAC program. In addition, new antenna developments in the VOR area may further decrease the siting advantage now enjoyed by TACAN; especially the VOR stacked array.

ALASKAN REGION AND DOMESTIC STATIONS COMPARISON

OF

NAVAIDS PROJECTS COSTS (SINGLE)

Project	Order 6011.3	Alaska Est.	Cost Ratio AL/6011.3	O&M Costs (Alaska)
Establish VORTAC	$415.0K	$2160.0K*	52	$27.2K
Establish VOR/DME	$235.6K	$2030.0K*	82	$27.2K
Establish TACAN	$297.7K	$ 850.0K	28	$12.0K
Establish NDB/DME	$195.0K	$ 853.6K	4.4	$14.2K
Establish NDB/TACAN	$302.6K	$ 989.4K	3.3	$15.8K
Add DME to NDB	$ 62.1K	$ 315.0K	5.0	$14.2K
Add TACAN to NDB	$221.2K	$ 450.6K	2.0	$15.8K
Establish NDB/Z Marker	$ 46.5K	$ 289.5K (Min) $ 634.5K (Max)	6.2 (Min) 13.6 (Max)	$ 3.8K

*Could be increased by $330K if in remote area.

TABLE I-1

COMPARISON OF COST BREAKDOWN OF ALASKAN REGION NAVAID PROJECT

VS.

ALL REGION AVERAGE FOR SAME NAVAID PROJECTS

Item	$240.4K Order 6011.3 Establish Single VORTAC	$1487.8K Alaskan Region Cost for Est. VOR/DME	$46.5K Order 6011.3 Establish NDB/Z Marker	$634.5K Alaskan Region Establish NDB/Z Marker
Engineering	6%	6%*	11%	6%*
Construction	19.7%	85%**	33%	85%**
Installation (Electronic)	12.3%	8.5%	5%	8.3%*
Flight Inspection	5.7%	0.5%	3%	0.6%
W.O. Const. Material	28.2%	Not Provided	8%	Not Provided
W.O. Electronic Equipment	24.5%	Not Provided	39%	Not Provided
Freight	3.3%	Not Provided	1%	Not Provided

*These figures were provided combined. This cost was arbritarily made percentage wise. Equal to the all region average.

**These figures represent the sum of those elements provided by the Alaskan Region which make up the construction construction cost elements for the regional average. This figure could increase or decrease a few percentage points if facility is located in a remote area or close to reliable power source.

TABLE I-2

2.0 AVIONICS. Volume II details the type, number, and distribution of avionics presently being used in Alaska. The important facts are:

a) Approximately one-third (1/3) of the aircraft do not report any type of navigation avionics. It is assumed that this situation exists not because of the lack of adequate NAVAIDs but due to a lack of necessity.

b) Of the remaining aircraft, about two-thirds (2/3) are equipped with VOR, one-half (1/2) have both ADF and VOR.

c) Almost none are DME equipped.

Therefore, it can be concluded that an Omega, Loran-C, or TACAN solution would be a considerable retrofit for the entire user community except, of course, the military with respect to TACAN. Tables I-3 through I-8 categorize the different types of avionics presently on the market. Each type has been further segregated into general groups which are felt to be in the price range and requirements of general aviation, executive or business aviation, and air carrier.

The rationale of upgrading present NDBs with DMEs is basically;

a) the cost of adding DME ground stations to existing NDBs is not excessive.

b) the benefits derived from co-locating a DME are substantial at certain terminals. It also allows a measure of backup to the inherently unstable LF frequencies used for NDBs.

c) If and when the present system is replaced, DMEs are always valuable when co-located with landing aids. These equipments would also be useful to RNAV systems having a multi-DME capability.

NAV RECEIVERS - VHF (PANEL-MOUNTED)*

(Price Range $1,020 - $4,500, uninstalled)

MOST PROBABLE USER	MANUFACTURER	MODEL	PRICE
General Aviation	Becker	NR 2029	$1,425
	Bendix	RN 242A	$1,495
	Collins	VIR-351	$1,614
	Dynair	Radair 200	$1,390
	Edo	R-552	$1,090
	Edo	R-662	$1,190
	Edo	R-772	$1,820
	Narco	NAV-11	$1,020
	Narco	NAV-12	$1,175
	Narco	NAV-111	$1,295
	Narco	NAV-14	$1,320
	Narco	NAV-112	$1,395
	Narco	NAV-114	$1,545

TABLE I-3

NAV RECEIVERS - VHF (PANEL MOUNTED)*

(Price Range $1,020 - $4,500, uninstalled)

(Continued)

MOST PROBABLE USER	MANUFACTURER	MODEL	PRICE
Executive or Business	Becker	NR 2030	$3,250
	Becker	NR 2020/40	$4,350
	RCA	AVN-221A	$3,000
	RCA	AVN-211A	$3,200
	RCA	AVN-220A	$4,300
	RCA	AVN-210A	$4,500

*Some models do not feature glide slope capability.

TABLE I-3a

ADF RECEIVERS*

(Price Range $995 - $9129, Uninstalled)

Most Probable User	Manufacturer	Model	Price
General Aviation	Cessna/ARC	546A	$1,395
	Cessna/ARC	446	$1,995
	Bendix	ADF T-12C	$1,157
	Bendix	ADF T-12D	$1,414
	Edo	R-556D	$ 995
	General Aviation	Sigma 1500	$1,149
	King	KR 86	$ 995
	King	KR 85	$1,395
	Narco	PDF	$1,195
	Narco	ADF-140	$1,495

TABLE I-4

ADF RECEIVERS*

(Price Range $995 - $9129, Uninstalled)
(Continued)

Most Probable User	Manufacturer	Model	Price
Executive or Business	Becker	AD 2050	$2,300
	Becker	AD 2060	$3,250
	Bendix	DFA-74A	$3,948
	Cessna/ARC	R-846A	$2,995
	King	KDF-8000	$3,130
	King	KDF 805	$3,370
Air Carriers	Bendix	DFA-73	$7,560
	Collins	DF 206	$9,129
	Marconi	AD 370B	$6,000
	Marconi	AD 380	$5,000

*All units are equipped with fixed-loop antennas and have goniometer indicators. Most have RMI compatibility, are digitally tuned, and have self-test

TABLE I-4a

NAVCOM RECEIVERS - VHF*

(Price Range $895 - $2,795, uninstalled)

MOST PROBABLE USER	MANUFACTURER	MODEL	PRICE
General Aviation	Cessna/ARC	RT-308C	$1,795
	Cessna/ARC	RT-328D	$1,995
	Cessna/ARC	RT-428A	$2,795
	Edo	RT-553	$1,195
	General Aviation	Alpha/500	$1,400
	General Aviation	Alpha/600	$1,650
	King	KX 145	$ 895
	King	KX 170B	$1,995
	King	KX 175B	$2,085
	Narco	Com 10A/Nav 10	$1,510
	Narco	Com 110/Nav 110	$1,845

*All are solid state, digitally controlled, and have self-test circuitry. Most prices include receiver-transmitter, converter, indicator, and mounts.

TABLE I-5

DISTANCE MEASURING EQUIPMENT*

(Price Range $2,480 - $15,174, uninstalled)

MOST PROBABLE USER	MANUFACTURER	MODEL	PRICE
Executive or Business	Collins	DME 40	$ 5,678
	King	KN 65	$ 2,495
	King	KDM 705A	$ 4,995
	Narco	DME 190	$ 2,480
Air Carrier	Collins	860E	$15,174
	King	KDM 7000	$10,339
	RCA	AVQ-85	$ 6,720

*Most units may be coupled to any RNAV system. Antenna and installation kits not included in the price of most of the above units.

TABLE I-6

RNAV SYSTEMS*

(Price Range $1,995 to $48,000, uninstalled)

MOST PROBABLE USER	MANUFACTURER	MODEL	PRICE
General Aviation	King	KN 74	$1,995
	King	KNC 610	$2,895
	Narco	CLC 60A	$2,195
Executive or Business	Airdata	AD 611	$3,400
	Bendix	RNS-3400B	$6,911
	Bendix	RNS-3500B	$8,861
	Collins	ANS-31	$8,028
Air Carrier	AiResearch	AiRNAV	$48,000
	Butler National	BNS-3D-RNAV	$23,950
	Collins	NCS-31	$13,416
	Edo	TCE 71A	$24,995
	Hamilton Standard	HSN-720 3D	$12,500
	King	KNR 665	$11,200

*All units are solid state. Prices do not include automatic data-entry units (ADEU). These cost from $5,000 to $8,000 more.

TABLE I-7

LONG RANGE NAVIGATION SYSTEMS

(Price Range $6,000 - $120,000, uninstalled)

MOST PROBABLE USER	MANUFACTURER	MODEL	SYSTEM TYPE**	PRICE
General Aviation	Dynell	Mark III	Omega	$ 6,000
Executive of Business	*Canadian-Marconi	CMA-719C	Omega	$ 50,000
	*Collins	INS-61B	INS	N.A.
	*Communications Components	VLF-1000-2	VLF	$ 27,775
	*Communications Components	VLF-1000-3	VLF	$ 30,250
	*Global Navigation	GNS-500	VLF	$ 43,000
	Northrop	AN/ARN-99	Omega	N.A.
	*Northrop	Cardinal 1	Omega	$ 40,000
	*Singer Keorfott	Gamma 1	INS	N.A.
Air Carrier	Litton	LTN-51	INS	$117,500
	Litton	LTN-104	INS/RNAV	$120,000

**While it is believed that the most probable user os these systems are as shown, it is probable that air carriers may also consider buying the annotated units.*

**LEGEND: Inertial Navigation System, VLF-Very Low Frequency, RNAV-Area Navigation

TABLE I-8

APPENDIX II

DIFFERENTIAL OMEGA IN ALASKA

1.0 GENERAL. There are four reasons that seem to recommend serious consideration of Differential Omega as a navigation system for Alaska.

A. Anticipated aircraft position accuracy provided should meet requirements for Alaska.

B. The cost of installation of sixteen differential stations would be less than $2 million.

C. Redundant equipment and installation at existing facilities will ease maintenance problems.

D. The system has an inherent "fail safe" characteristic in that a failure of a differential station would still permit navigation with the basic Omega signals, but with a decrease in accuracy. In such a situation, accuracy may decrease with time as the last received differential correction became less valid.

In the selection of potential sites for locations of Differential Omega stations in Alaska the following criteria were used:

A. The radius of operation for valid differential corrections is 150 nautical miles.

B. There must be existing facilities at the site.

C. Terrain features within the radius of operation must not extensively block the correction signal.

D. Sites must be close enough to each other to provide as complete coverage as possible.

The listing of recommended sites in the order of suggested installation* Sites 1, 2, and 3 will cover the area north of the Brooks Range; and are apparently the most difficult installations. By proceeding in the suggested order, the area of coverage would start at the north, spread southward, then extend along the Aleutian Island chain. The following tables include the recommended sites, suggested alternate sites and comments on each site: (See Table 1 and Figure 1)

*This implementation sequence does not consider an operational feasibility network of 3 stations suggested for early evaluations.

DIFFERENTIAL OMEGA GROUND STATION SITES

ORDER OF INST.	NAME	CALL SIGN	LATITUDE	LONGITUDE	EXISTING FACILITIES	AIR-PORT	ELE.	COMMENT
1	Umiat	UMT	69° 23'	152° 10'	Comm - tie-in FSS	Yes	352	Unattended airport Mountain ridges N & S
1A Alternate	Prince Creek		69° 22'	153° 17'	Comm - tie-in FSS	Yes	1000	Unattended airport Acft with large tires only
1B Alternate	Knifeblade Ridge		69° 09'	154° 45'	Comm - tie-in FSS	Yes	1380	Unattended. Runway on ridge
1C Alternate	Lonely DEW Station	LNI	70° 55'	153° 14'	RBn(H) 316 Radio 236.6 SSFO 122.2	Yes	29	Airport closed to public
2	Point Lay	PIZ	69° 44'	163° 01'	RBn(H) 251 Radio 236.6 SSFO 122.2	Yes	20	Airport closed to public
2A Alternate	Wainwright DEW Station	AIN	70° 37'	159° 51	RBn(H) 266 Radio 236.6 SSFO 122.3	Yes	88	Airport closed to public. Unattended
2B Alternate	Cape Lisburne	LTR	68° 53'	166° 07'	RBn(HW) Radio 236.6 SSFO 122.3	Tes	12	Closed to public. Located at base of steep mountain.
3	Barter Island DEW Station	BTI	70° 08'	143^{0} 35'	RBn(H) 308 Radio 236.6 SSFO 122.2	Yes	5	
3A	Komakuk Beach	AJ	69° 36'	140° 10'	RBn(H) 239 Radio 236.6	No	24	

DIFFERENTIAL OMEGA GROUND STATION SITES

ORDER OF INST.	NAME	CALL SIGN	LATITUDE	LONGITUDE	EXISTING FACILITIES	AIR-PORT	ELE.	COMMENT
4	Ralph Calhoun (Tanana)	TAL	65° 10'	152° 07'	VOR 116.6 RBn(BH) Radio 123.6	Yes	28	
5	Ralph Wein Mem. (Kotzebue)	OTZ	66° 53'	162° 36'	VORTAC RBn(BH) Radio	Yes	11	Airport attended.
6	Fort Yukon	FYU	66° 34'	145° 15'	VORTAC RBn(BH)	Yes	431	Airport attended on request.
7	Unalakleet	UNK	63° 53'	160° 48'	VORTAC LFR	Yes	21	Airport attended.
8	Farewell	FWL	62° 31'	153° 54'	RBn(BH) Radio 123.6	Yes	1535	Airport attended. Mountainous terrain.
9	Gulkana	GKN	62° 09'	145° 27'	VORTAC LFR Radio	Yes	1578	Attended daylight.
10	Bethel	BET	60° 47'	161° 50'	VORTAC RBn(BH)	Yes	131	Airport attended.
11	Homer	HOM	59° 38'	151° 29'	VORTAC LFR Radio	Yes	78	Airport attended.
12	King Solomon	AKN	58° 41'	156° 39'	VORTAC LFR Radio	Yes	57	Airport attended.

DIFFERENTIAL OMEGA GROUND STATION SITES

ORDER OF INST.	NAME	CALL SIGN	LATITUDE	LONGITUDE	EXISTING FACILITIES	AIR-PORT	ELE.	COMMENT
13	Cold Bay	CDB	55° 12'	162° 43'	VORTAC ILS Radio	Yes	98	
14	Umnak	UNS	53° 22'	167° 54'	RBn(W) Comm - to FSS	Yes	127	Airport attended.
15	Adak	ADK	51° 53'	176° 39'W	TACAN RBn(H)	Yes	19	Non-military acft. operations limited
16	Shemya	SYA	52° 43'	174° 05'E	TACAN RBn(H) ILS	Yes	97	Attended 24 hours. Official business only.

2.0 SYSTEM OPERATION. There are two major components in a complete differential Omega system:

1. The Omega transmitters located around the world.

2. The Differential Omega stations in local areas.

Navigation will be possible with the basic Omega signals, and more accurately, with the application of differential corrections to the basic signals. In actual operation, an aircraft would successively be within the coverage areas of several differential stations along its route. To be manageable the signal from each available differential station must be received separately in the aircraft. There are two apparent ways to achieve the required signal separation:

1. Have each differential station transmit on a frequency unique to itself, within its area of operation. Two widely separated stations could use the same VHF frequency and not cause interference, just as VOR stations presently operate. Separations of 400 miles or more would be acceptable.

2. Have each station within an area transmit its identified signal in a time ordered sequence with the other stations.

The advantages of the time sequenced method is that all differential stations would be on one frequency, and the pilot workload involved in changing frequencies would be eliminated. However, the airborne equipment would have to be able to select the desired differential station correction values from the undesired values received on the common frequency. With a station identifier included before the correction values, it would be relatively simple to automatically select the desired values in the aircraft and ignore others. The common time standard needed to accomplish time ordered operation would be available from the received Omega signals which are synchronized by atomic oscillators.

With the ability to select corrections from desired differential stations, the method of transition from one station's coverage area to another must be considered. It must be determined whether the best method is to switch abruptly from station "A" corrections to those of station "B" values when midway between the stations. Operational procedures will be examined as part of the development program. Table 2 shows a time ordered format in which the differential stations could transmit on the same frequency without mutual interference. Incorporation of the sixth segment will permit system changes; and it can be used for maintenance and testing activities.

TABLE 2 - TIME-ORDERED TRANSMISSION SEQUENCE

TIME SEGMENT NUMBER

	1	2	3	4	5
Stations Transmitting	(1) UMIAT	(2) PT. LAY	(4) R. CALHOUN	(5) R. WEIN	(9) GULKANA
	(7) UNALAKLEET	(8) FAREWELL	(10) BETHEL	(6) FORT YUKON	(3) BARTER IS.
	(11) HOMER	(13) COLD BAY	(14) UMNAK	(12) KING SALMON	(16) SHEMYA
				(15) ADAK	

Total duration of the six time segments is not established; it is dependent on the required rate of correction messages and on the necessary message duration imposed by technical limitations at the transmission technique used. If all six segments could be included in a ten second overall period (i.e., 1.66 second per segment) then correction messages could be transmitted with each new measurement of Omega signals, which also occur once every ten seconds. However, corrections may not be needed that frequently.

Some consideration must be given to the radio frequency band and the signal on which the differential corrections are transmitted. The most apparent options are:

1. A VHF communications frequency (both digital and voice)

2. Encoding corrections on the DME pulse train

3. An NDB frequency

4. A VOR frequency

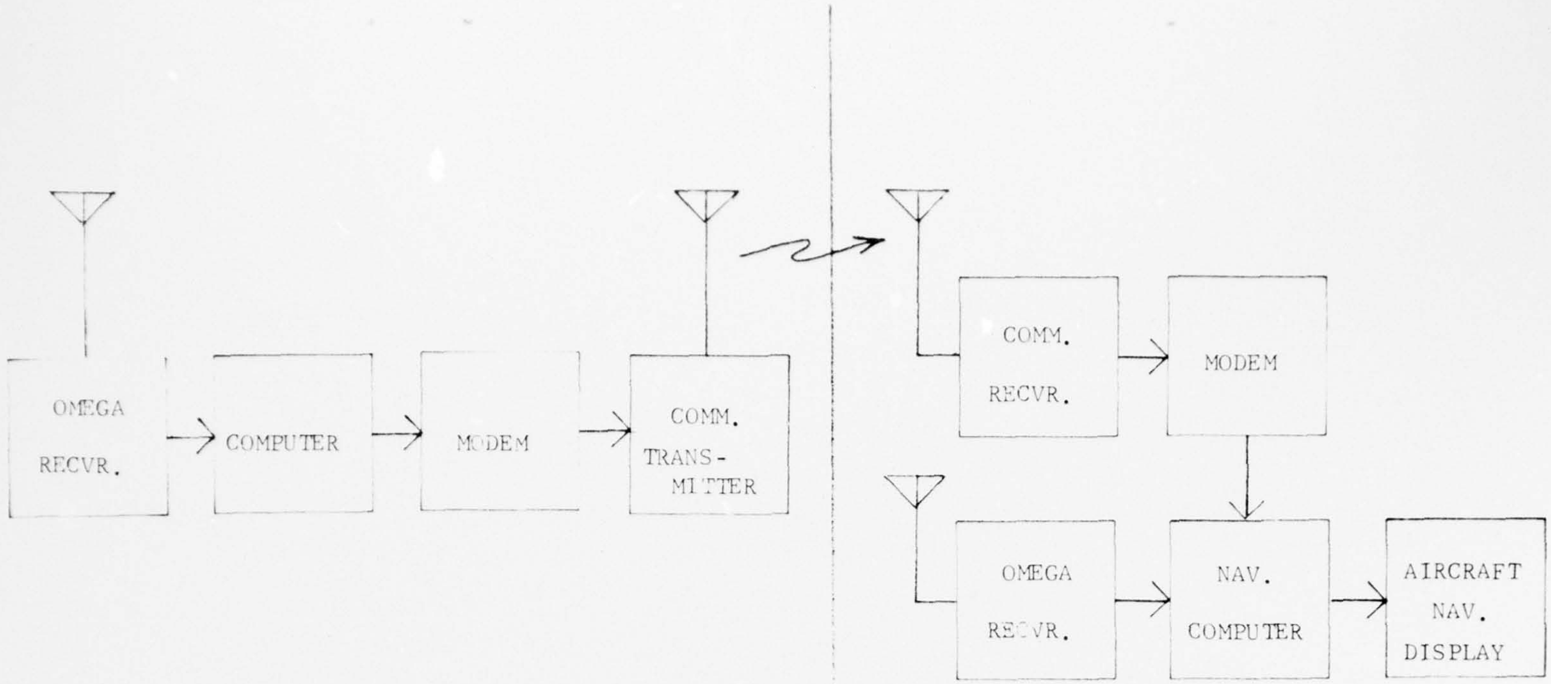
A major consideration in the selection of the frequency to be used, as noted earlier, is signal blockage by terrain features. Early evaluation systems will use a VHF communication frequency for convenience, but the use of VHF should not be considered as an essential part of Differential Omega. The time sequencing of corrections on a single low frequency (LF) carrier might be advantageous in Alaska. Another possibility would be to include corrections in the digital data broadcasts from TACAN/DME stations.

3.0 MAINTENANCE. Figure 2 is a simplified block diagram of both halves of the Differential Omega system, the ground station is on the left and an airborne unit is on the right. Redundant units in the ground station and use of equipment already developed should assure reliable operation. Since the equipment is not large, maintenance would be accomplished by unit replacement rather than component changes or onsite adjustments.

4.0 SCHEDULE. In the Alaska area, four of the eight Omega stations would be most used. They are: Norway, Japan, North Dakota, and Hawaii. Signals from Liberia and Australia might also be useful if present in adequate amplitude. Development and evaluation of the Differential Omega technique by the FAA will proceed through feasibility and operational type phases. The report on the feasibility tests will be completed by mid-1977. Evaluation of the operational type system will be completed by mid-1980. If orderly processes are followed, system implementation would begin after completion

of the operational type system evaluation. It would be possible to advance the implementation schedule by proceeding with a procurement when initial results of the operational type system evaluation are available and, if they show significant indication of success. In this situation, the ground stations might be available for first installations in early 1980. A much higher risk decision could be made on the basis of feasibility model evaluation results, but that would not be recommended unless the need was urgent.

5.0 COSTS. The estimated cost of each Differential Omega ground station, exclusive of shelter and power, will be approximately $75,000. Included in the ground station would be two complete sets of required electronic equipment with automatic switching when one set fails. Total cost of sixteen sets of duplicate ground station equipment and four spare single sets, would be about $1,350,000. Available shelter and power would probably serve in all installations since the equipment would not be large. Cost for installation would be about $10,000 per station or $160,000 for the complete system. The total cost for the ground station system, then, would be approximately $1,510,000. Cost of airborne equipment would depend on the complexity of the equipment desired. It is estimated that the most simple units would be available for $5,000, while the most sophisticated would cost about $40,000. The basic navigation capability would be left-right steering and distance to go from any point to any other point with an anticipated position accuracy between 0.25 and 0.50 nautical mile. The more expensive equipment would provide multiple waypoint storage and a variety of useful readouts. The low cost unit would provide basic steering to one or two points. Development lead time on the airborne equipment would be minimal because Omega receiver/computer systems are already in production, and use of the differential correction would chiefly involve software changes. Addition of the interface to accept differential correction messages from the ground would be required.



DIFFERENTIAL OMEGA - GROUND STATION

DIFFERENTIAL OMEGA - AIRBORNE UNIT

FIGURE II-2

APPENDIX III

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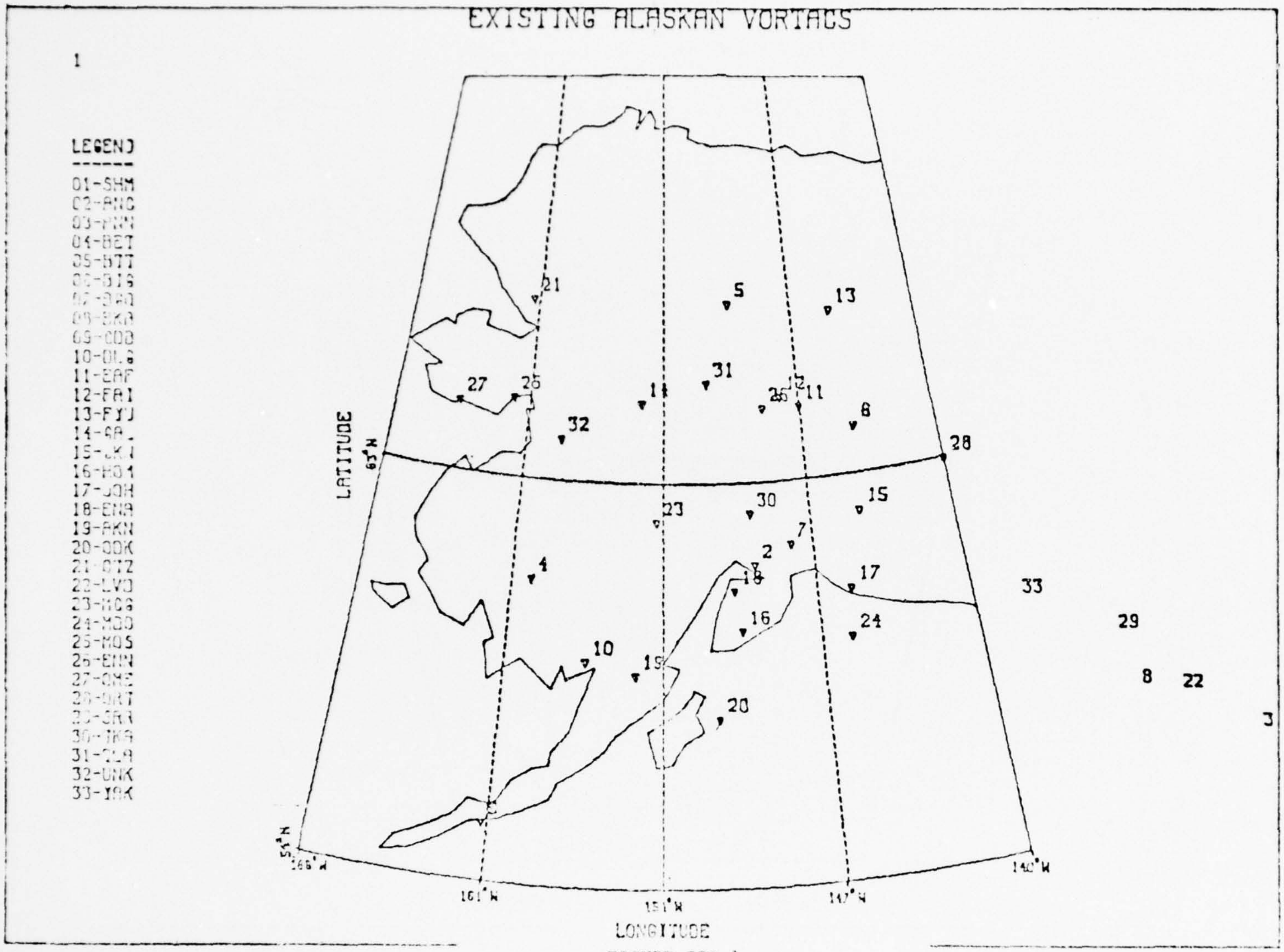
EXISTING ALASKAN VORTACS
1
LEGEND
01-SHM
02-ANC
04-BET
05-BTT
10-DLG
11-EAF
12-FAI
13-FYU
18-ENA
19-AKN
20-ODK
25-MOS
32-UNK
33-YAK
LATITUDE
63°N
LONGITUDE
166°W
161°W
151°W
147°W
140°W

FIGURE III-1

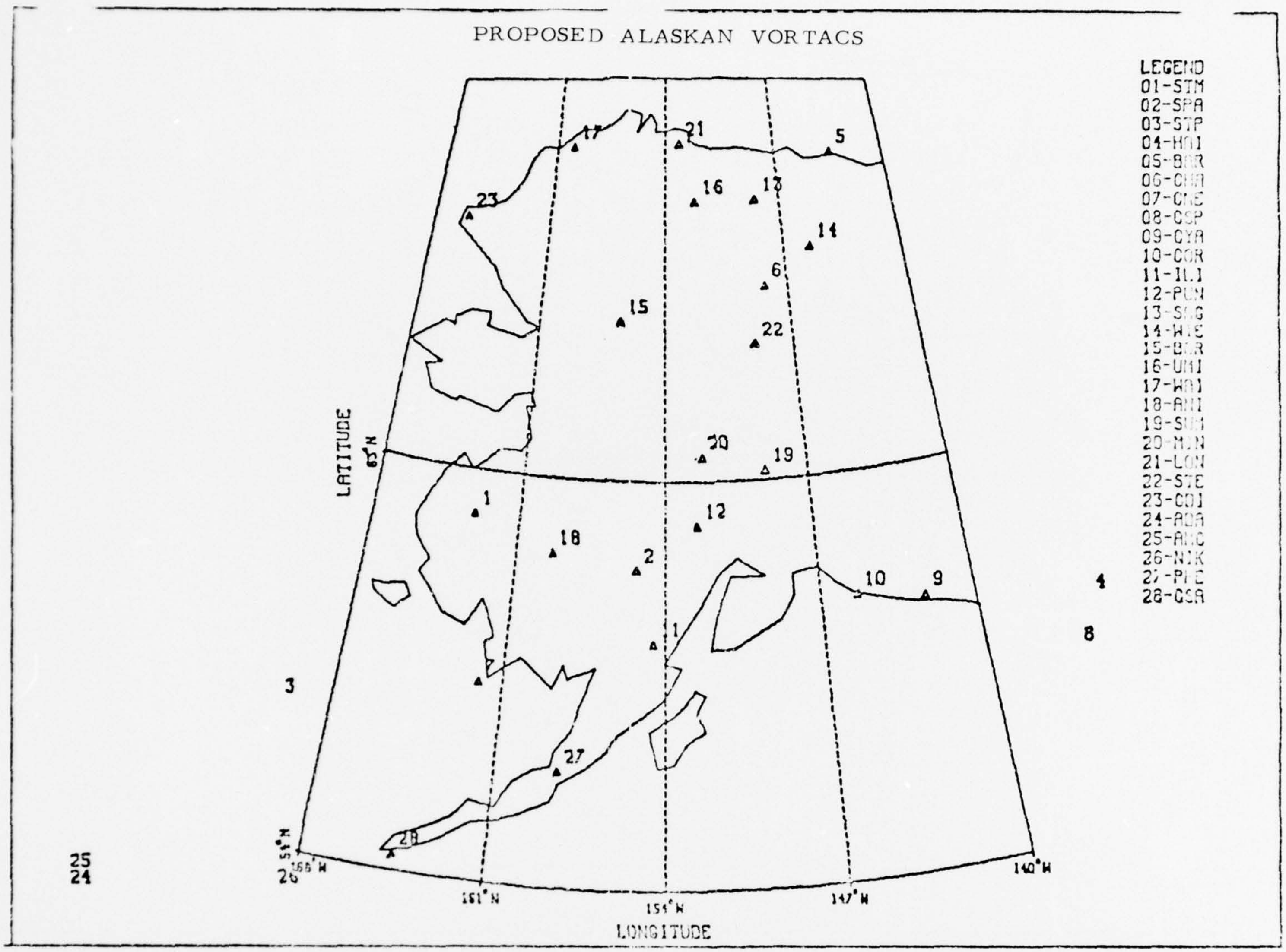
PROPOSED ALASKAN VORTACS
LEGEND
01-STM
02-SPA
03-STP
04-HNI
05-BRR
06-CHR
07-CNE
08-CSP
09-CYR
10-COR
11-ILI
12-PUN
13-SAG
14-WIE
15-BKR
16-UMI
17-WAI
18-ANI
19-SUM
20-MIN
21-LON
22-STE
23-COI
24-ADA
25-ANC
26-NIK
27-PFE
28-CSR
LATITUDE
65°N
55°N
LONGITUDE
168°W
161°W
154°W
147°W
140°W

FIGURE III-2